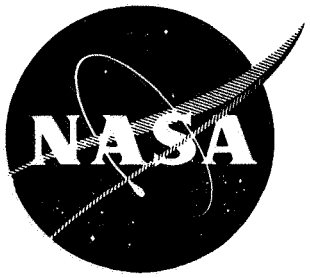
NASA CR-72593
DAC-61001-F



FINAL REPORT

DEVELOPMENT OF IMPROVED ZINC ELECTRODES FOR SECONDARY BATTERIES

by

A. Himy

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS 3-11830

ASTROPOWER LABORATORY
McDonnell Douglas Astronautics Company
Western Division

Requests for copies of this report should be referred to

National Aeronautics and Space Administration
Office of Scientific and Technical Information
Attention: AFSS-A
Washington, D. C. 20546

NASA CR-72593
DAC-61001-F

FINAL REPORT
July 1968 to July 1969

DEVELOPMENT OF IMPROVED ZINC ELECTRODES FOR SECONDARY BATTERIES

by

A. Himy

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

July 1969

CONTRACT NAS 3-11830

Technical Management
NASA Lewis Research Center
Cleveland, Ohio
Direct Energy Conversion Division
William A. Robertson

ASTROPOWER LABORATORY
McDonnell Douglas Astronautics Company
Western Division
Newport Beach, California

DEVELOPMENT OF IMPROVED ZINC ELECTRODES FOR SECONDARY BATTERIES

by

A. Himy

ABSTRACT

A new zinc electrode construction was evaluated, based on an inorganic material mixed with zinc oxide, which acted as a binder when the mix was sintered at 850°C. Zirconia was selected over two other inorganic materials; proportions ranging from 2% to 50% were investigated for physical characteristics and from 5% to 20% for electrical characteristics. PbO was investigated as an additive, besides the usual 2% HgO amalgamation. A total of 20 combinations of construction features were electrically tested on three different cycling regimes. In general, zinc shape retention was improved in varying degrees, reflected in longer cycle life over the regular unsintered zinc oxide electrode.

CONTENTS

FIGURES

TABLES

DEVELOPMENT OF IMPROVED ZINC ELECTRODES FOR SECONDARY BATTERIES

by A. Himy

Astropower Laboratory
McDonnell Douglas Astronautics Company
Western Division

SUMMARY

The objectives of this program are to develop and test particular zinc electrode constructions that may result in long cycle life.

The various fabrication techniques encompass one basic and common feature – the use of a refractory type inorganic material mixed with zinc oxide in a particular ratio and sintered at very high temperatures so as to result in a mechanically strong electrode capable of maintaining its structural integrity during handling and cell assembly. This electrode is expected to perform satisfactorily during electrical testing because of a possible better shape retention resulting from less "slumping."

INTRODUCTION

This program consists of two distinct tasks.

Task I covers electrode fabrication techniques and physical characterization. The basic and common feature of the new zinc electrode constructions was the use of refractory type inorganic material (silicate or oxide) mixed with zinc oxide and acting as a binder after sintering the mix at high temperatures. Starting with three different inorganic materials, and several ratios of zinc oxide and inorganic material, the investigation was carried out on pellet-type samples simulating a section of the electrode. Sintering temperatures ranging from 300°C to 1400°C were investigated. The physical characteristics studied were density, absorption, porosity, surface area by BET measurement, and pore size distribution by mercury intrusion. At the

end of this phase, out of all the variables encountered, a selection of 20 combinations was made for use in actual cells for electrical testing on the next task.

Task II covered the testing of approximately 250 cells on three different regimes — 1 hr, 1.5 hr, and 24 hr cycling periods with the first one at 100°C and the others at 25°C.

The cells were first submitted after formation to four deep discharge cycles at various rates ranging from 30 mA to 3 A. Because the test cell was purposely designed to be quickly zinc limited to accelerate failure, the data obtained are indicative only on a relative merit basis. Compared with the control electrode (unsintered zinc oxide), which reached about 500 cycles on the 1.5 hr cycling period, the best electrode among all combinations fully tested completed about 650 cycles. However, the technical performance period of the program was completed before all test data on other combinations were acquired.

The author wishes to acknowledge the valuable contribution of Mr. I. C. Blake, Manager of the Battery Fabrication and Development Department, for the close supervision of the manufacture of cell components and assembly of cells, and of Mr. A. D. Taylor for setting up and following up the cell testing. Special acknowledgement is also given to Mr. G. Boehm who performed the laboratory analytical work and compiled the test data.

TASK I — PHYSICAL CHARACTERIZATION

Task I covered electrode fabrication techniques and electrode characterization for physical properties.

The general lines of investigation are as follows:

Three inorganic materials are to be studied. Each is to be blended with zinc oxide in various proportions ranging from 2% to 50% and the mix is to be sintered at a temperature where physical strength of the electrode is attained. The sintering temperature is to range from 300°C to 1400°C. This necessitates making a selection of electrode grid metal (silver melts at 960°C) and, consequently, a selection of the mix process and electrode fabrication technique. In turn, the method of incorporating the additives to be investigated (HgO, PbO) is dependent upon the final temperature selected, since HgO decomposes at 500°C and PbO melts at 888°C.

All phases of this investigation proceeded almost concurrently and are therefore not presented chronologically.

Grid Metal Selection

Metals other than silver (melting point 960°C) were first considered for their high melting points, higher than the sintering temperatures of inorganic materials. They were:

Molybdenum:	2610°C
Tungsten:	3410°C
Tantalum:	2996°C

However, their electrochemical compatibility with zinc must be taken into account.

Potentials of these metals were measured versus a zinc metal strip in various solutions ranging from 30% to 40% pure KOH or zincate saturated KOH at 25°C. The range of values was as follows:

Molybdenum:	0.75 to 0.86 V
Tungsten:	0.69 to 0.77 V
Tantalum:	0.75 to 0.85 V

Once the metals were zinc plated, all potentials dropped to a few millivolts.

However, when the metals were left in intimate contact with zinc metal in zincate saturated KOH solutions, gassing occurred in varying degrees and continued uninterrupted for the duration of the test (68 hours).

Following is a list of metals in decreasing order of reaction after 68 hours exposure to KOH and zinc:

Metal	Gassing	Metal Weight Loss	Zinc Weight Loss
Tungsten	Heavy	0%	59%
Molybdenum	Fine	0%	14%
Tantalum	None	0%	5%

Tantalum showed the greatest ability for the leads to be welded to the collector grid, using parent material. Tungsten was found to be very hard.

Another consideration is the electrical resistance offered by grids made of these metals compared with silver. Their electrical resistivities are:

Molybdenum:	5.70 $\mu\Omega$-cm
Tungsten:	5.60 $\mu\Omega$-cm
Tantalum:	13.85 $\mu\Omega$-cm
Silver:	1.59 $\mu\Omega$-cm

However, this is a minor cause for rejecting the metal because it is not likely to appreciably affect the electrical performance of the zinc electrode.

Another consideration is the handling of these materials at elevated temperatures. They oxidize very fast and must be handled in special set-ups in inert atmospheres.

In summary, all of these tests showed the unsuitability of the metals considered; the zinc corrosion caused by the metal contact in alkali is certainly the most important factor for rejection.

It appears without going too far in the search for new grid metals that silver remains the preferred material. This justifies the various alternate approaches for sintering processes. Variation of the silver grid structure will be considered rather than variation of the metal.

Fabrication Techniques

Materials

The three inorganic materials first considered are the following:

Material	Code
Magnesium silicate complex	OL
Zirconia	Z
Magnesia	M

OL is a material previously used on NASA Contract NAS 3-8513* which showed promising results in terms of cycling performance at 100°C. The zirconia and magnesia were selected on the basis of compatibility with zinc in KOH solution in terms of gassing characteristics and electrochemical stability.

---

*A. Himy, "Improved Zinc Electrode," Final Report NASA CR-72265, Astropower Laboratory, Missile & Space Systems Division, Douglas Aircraft Company, July 1967.

Ratio

The following ratios were considered:

ZnO	Inorganic
98%	2%
90%	10%
80%	20%
65%	35%
50%	50%

However, in an actual cell, it would not be advantageous to go beyond 80/20 because of the excessive decrease in active material amount.

The code adopted for a particular mix is given in the following example: 80/20 Z means 80% ZnO blended with 20% zirconia.

Process

General

Sintering the mix powder covers a wide range of temperatures that extend from 300° up to 1400°C. Modification of the bond structure may occur at the high temperature range. Therefore, the sintering process will follow two parallel paths.

In the normal process (N), the electrode is first pressed as usual, then sintered at a temperature that must be compatible with the grid metal (no melting or severe distortion due to heat should occur) and with the additives (HgO decomposes at 500°C and PbO melts at 888°C).

In the presintered process (PS), the powder mix is sintered in compacted form, ground fine and sifted. In this step, the sintering temperature can be as high as necessary to create the desired bond structure between particles of different materials.

At this stage two possibilities are offered:

(a) Blend the additive dry with the mix in the required percentage; press the electrode; then submit it to a relatively low heat treatment (below 500°C because of the presence of HgO) for an extra bond between presintered particles; or,

(b) Press the electrode first; sinter at the desired temperature; then introduce the additives by a wet process.

However, the possibility (a) was abandoned early in the course of this investigation because the presintered mix failed to develop a bond between particles below 500°C. Consequently, only possibility (b) was adopted.

Material Preparation

The preparation of materials and mixes in various percentages involves a long and careful procedure. All blends are done by ball milling with a certain amount of various organic additives for proper processing.

A batch of zinc oxide and inorganic material blend of 1500 grams is mixed with 2000 cm^3 of water to which are added 2% Carbowax, 0.5% dextrine, and 0.01% anti-foam agent. The mixture is then ball milled for 15 hours, then strained through a 325 mesh screen and dried at 105°C for over 72 hours.

The material is then granulated and sifted through -32 to +80 mesh screen in order to keep the size of particle agglomerates in a relatively narrow range.

This general procedure changes very little, only in the quantities of organic additives and water, for each material composition and ratio.

At this point, either the electrode is pressed then sintered, or the powder is sintered then pressed into electrodes. The sintering temperatures are high enough to decompose all organic substances so that the resultant product is purely inorganic.

Pellet Fabrication

The physical measurements were done on pellets pressed to the apparent density, thickness, and weight per unit area as those of the final electrode. They were pressed without the use of grid or KT interseparator for the purpose of accurately characterizing the physical magnitudes called out in the work statement, i.e., density, absorption, surface area by the BET method, and pore size by Hg intrusion.

Two sizes were chosen as being practical for the characterization of the physical properties.

Circular pellets 1" in diameter and 0.050" in thickness (identical to electrode thickness) are made for measuring density, porosity, and water absorption.

Square pellets 3/8" x 3/8" x 0.050" are made with the same weight per unit area as the circular pellets for determining surface area by

the BET method and pore size distribution by mercury intrustion because of the maximum size required by the apparatus.

Physical Characteristics

Common to all materials and mix ratios are the following measurements and related computations on the 1" diameter pellets.

Before Sintering	
Original diameter	D_o
Original thickness	N_o
Original volume	V_o
Original mass	m_o
After Sintering:	
Diameter	D
Thickness	N
Volume	V
Mass	m
Weight loss percent	$W.\ L. = \frac{m_o - m}{m_o} \times 100$
Mass after impregnation with water	m'
Water pick-up	$\Delta m = m' - m$
Water absorption %	$a = \frac{\Delta m}{m} \times 100$
Apparent density	$d_a = \frac{m}{V}$
Measured porosity %	$p_m = a \cdot d_a$
True density (composite)	d_c (given in Table X)
Calculated porosity %	$p = \frac{d_c - d_a}{d_c} \times 100$

The difference $\Delta p = p - p_m$ will give the percentage of closed or nonconnected pores, i.e., not accessible to electrolyte.

The shrinkage factor is defined as:

$$\sigma \quad \frac{V_o - V}{V_o} \times 100$$

At least two samples per set of conditions were run and averages are presented for the magnitudes defined above for each inorganic material as well as for pure zinc oxide.

The temperatures run in the first stage were 300°C, 500°C, 700°C, 900°C. In the second stage: 1000°C, 1200°C, 1400°C. The sintering time was held constant (1 hour) to avoid introducing another variable.

Lower Temperature Range

Physical measurements, experimental data and calculated magnitudes, are given in table and graph forms for each material.

Material	Tables	Figures
OL	I, II	1 to 4
Z	III, IV	5 to 8
M	V, VI	9 to 12

Added for reference are Tables VII, VIII and Figures 13 and 14 for sintered pure ZnO.

Comments

Weight loss after sintering pellets with material OL and Z is less than 3%, which is approximately the amount of organic material introduced during the ball milling and granulation operations before sintering. For pellets with magnesia (M), the weight loss experienced is greater (when water is added to the mix for ball milling and granulation, magnesia is hydrated). Upon drying at 105°C, only free water is evaporated. Molecularly bonded water is removed only during the high temperature sintering operation. A confirmation of this phenomenon can be found in the good fit of the experimental weight loss percentage with the calculated loss of one water molecule. Selecting the pellets exposed to 900°C for 1 hour and correcting for the loss of organic binders, the data are presented in Table IX. Longer exposure at high temperature would smooth out the small differences if they are not experimental errors.

Pellets are relatively strong in the sintering range of 500° to 900°C with acceptable porosity.

For a given apparent density of the electrode, the water absorption and porosity are constant over a temperature range of 300° to 900°C.

For a given sintering temperature and apparent density, the porosity is constant regardless of the composition of the mix.

TABLE I

D_o = 1" PELLET PHYSICAL CHARACTERISTICS

Material: OL

$\Delta m = m' - m$

$$\text{weight loss \%} = \frac{m_o - m}{m_o} \times 100$$

Material	Ratio	Temp. °C	Before Sintering			After Sintering						
			N_o (mils)	V_o (c.c.)	m_o (g)	D (in.)	N (mils)	V (c.c.)	m (g) (dry)	m' (g) (wet)	Δm (g)	Weight Loss %
OL	98/2	300	48.0	0.617	1.593	1	48.0	0.617	1.572	disintegrated		1.3
		500	48.0	0.617	1.585	1	48.0	0.617	1.560	1.875	0.315	1.6
		700	49.0	0.630	1.590	1	48.5	0.624	1.566	1.882	0.316	1.5
		900	48.0	0.617	1.596	1	48.0	0.617	1.570	1.893	0.323	1.6
	90/10	300	49.0	0.630	1.609	1	49.0	0.630	1.580	1.879	0.299	1.8
		500	50.0	0.643	1.599	1	49.0	0.630	1.569	1.889	0.320	1.9
		700	51.0	0.656	1.604	1	49.0	0.630	1.571	1.893	0.322	2.1
		900	49.0	0.630	1.607	1	48.0	0.617	1.570	1.873	0.303	2.3
	80/20	300	48.8	0.628	1.600	1	48.0	0.617	1.571	1.855	0.284	1.8
		500	48.5	0.624	1.607	1	48.3	0.621	1.574	1.862	0.288	2.1
		700	48.5	0.624	1.599	1	48.3	0.621	1.564	1.859	0.295	2.2
		900	48.8	0.628	1.600	1	48.3	0.621	1.562	1.856	0.294	2.4
	65/35	300	52.8	0.679	1.572	1	52.5	0.675	1.529	1.844	0.315	2.7
		500	50.3	0.647	1.601	1	50.3	0.647	1.551	1.830	0.279	3.1
		700	49.5	0.637	1.604	1	49.3	0.634	1.548	1.819	0.271	3.5
		900	50.3	0.647	1.604	1	50.3	0.647	1.544	1.820	0.276	3.7
	50/50	300	54.5	0.701	2.027	1	54.5	0.701	1.973	2.177	0.204	2.7
		500	53.5	0.688	2.006	1	53.5	0.688	1.942	2.153	0.211	3.2
		700	52.5	0.675	1.970	1	52.5	0.675	1.900	2.116	0.216	3.6
		900	54.0	0.695	2.019	1	54.0	0.695	1.944	2.173	0.229	3.7

$a = \frac{\Delta m}{m} \times 100$

$d_a = \frac{m}{V}$

$p_m = a \cdot d_a$

TABLE II

D_o = 1" PELLETS

PHYSICAL CHARACTERISTICS II

Material: OL

$p = \frac{d_c - d_a}{d_c} \times 100$

$\Delta p = p - p_m$

$\sigma = \frac{V_o - V}{V_o} \times 100$

Material	Ratio	Temp. °C	a%	d_a (g/cc)	p_m%	d_c (g/cc)	p%	Δp%	σ%	
OL	98/2	300	—	—	—		—	—	—	Disintegrated
		500	20.2	2.53	51.1	5.40	53.2	2.1	0	
		700	20.2	2.51	50.6	5.40	53.5	2.9	1.0	
		900	20.6	2.54	52.3	5.40	52.9	0.6	0	
	90/10	300	18.9	2.51	47.5	5.13	51.1	3.7	0	
		500	20.4	2.49	50.8	5.13	51.5	0.7	2.0	
		700	20.5	2.49	51.1	5.13	51.4	0.3	4.0	
		900	19.3	2.54	49.1	5.13	50.4	1.3	2.1	
	80/20	300	18.1	2.55	46.0	4.83	47.3	1.3	1.8	
		500	18.3	2.53	46.4	4.83	47.5	1.1	0.5	
		700	18.9	2.52	47.5	4.83	47.9	0.4	0.5	
		900	18.8	2.52	47.3	4.83	47.9	0.6	1.1	
	65/35	300	20.6	2.27	46.7	4.45	49.1	2.4	0.6	
		500	18.0	2.40	43.1	4.45	46.1	3.0	0	
		700	17.5	2.44	42.7	4.45	45.1	2.4	0.5	
		900	17.9	2.39	42.7	4.45	46.4	3.7	0	
	50/50	300	10.3	2.81	29.1	4.12	31.7	2.6	0	
		500	10.9	2.82	30.7	4.12	31.5	0.8	0	
		700	11.4	2.81	32.0	4.12	32.0	0	0	
		900	11.8	2.80	32.9	4.12	32.9	0	0	

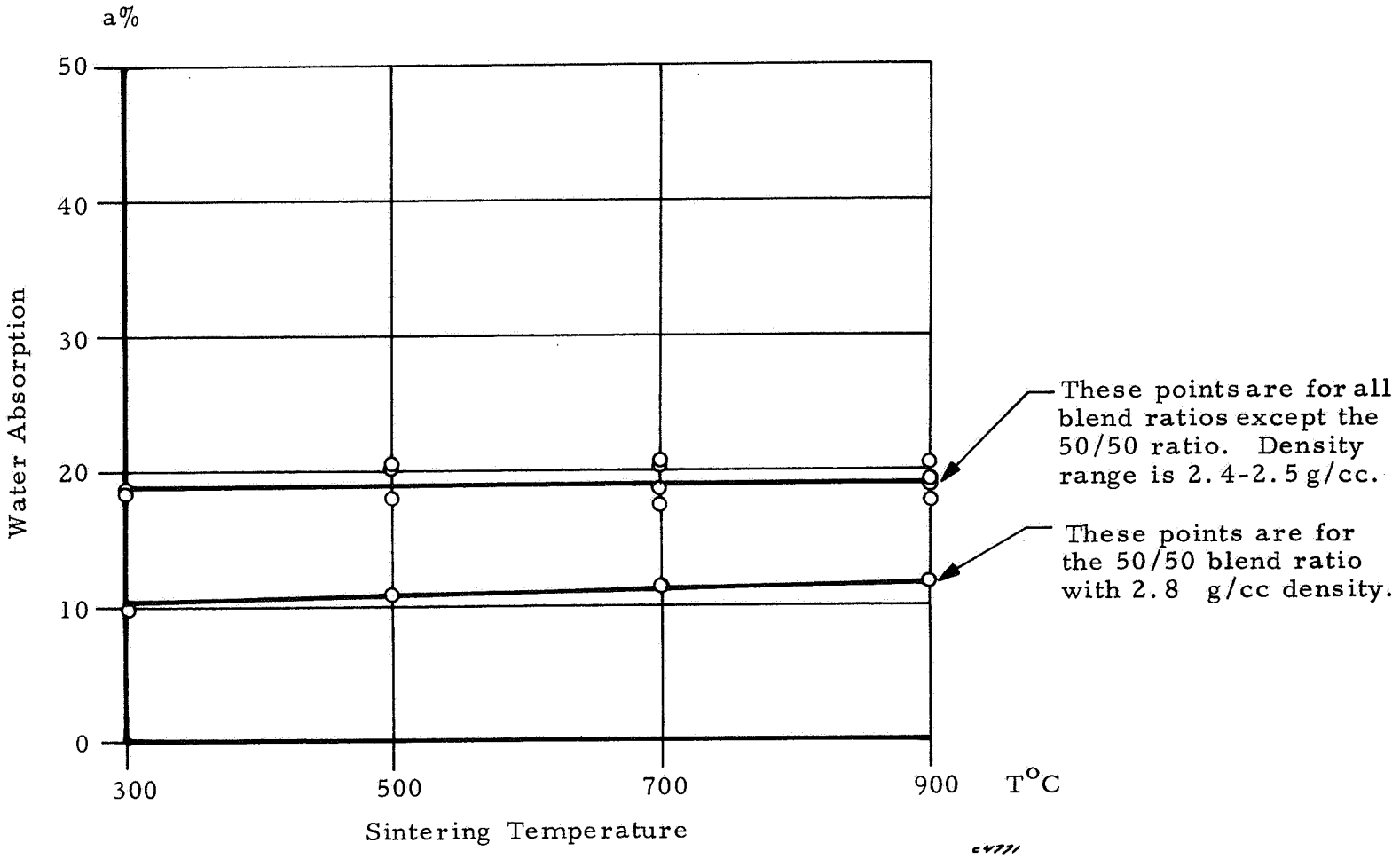


Figure 1. OL-Blends, Absorption vs Sintering Temperature

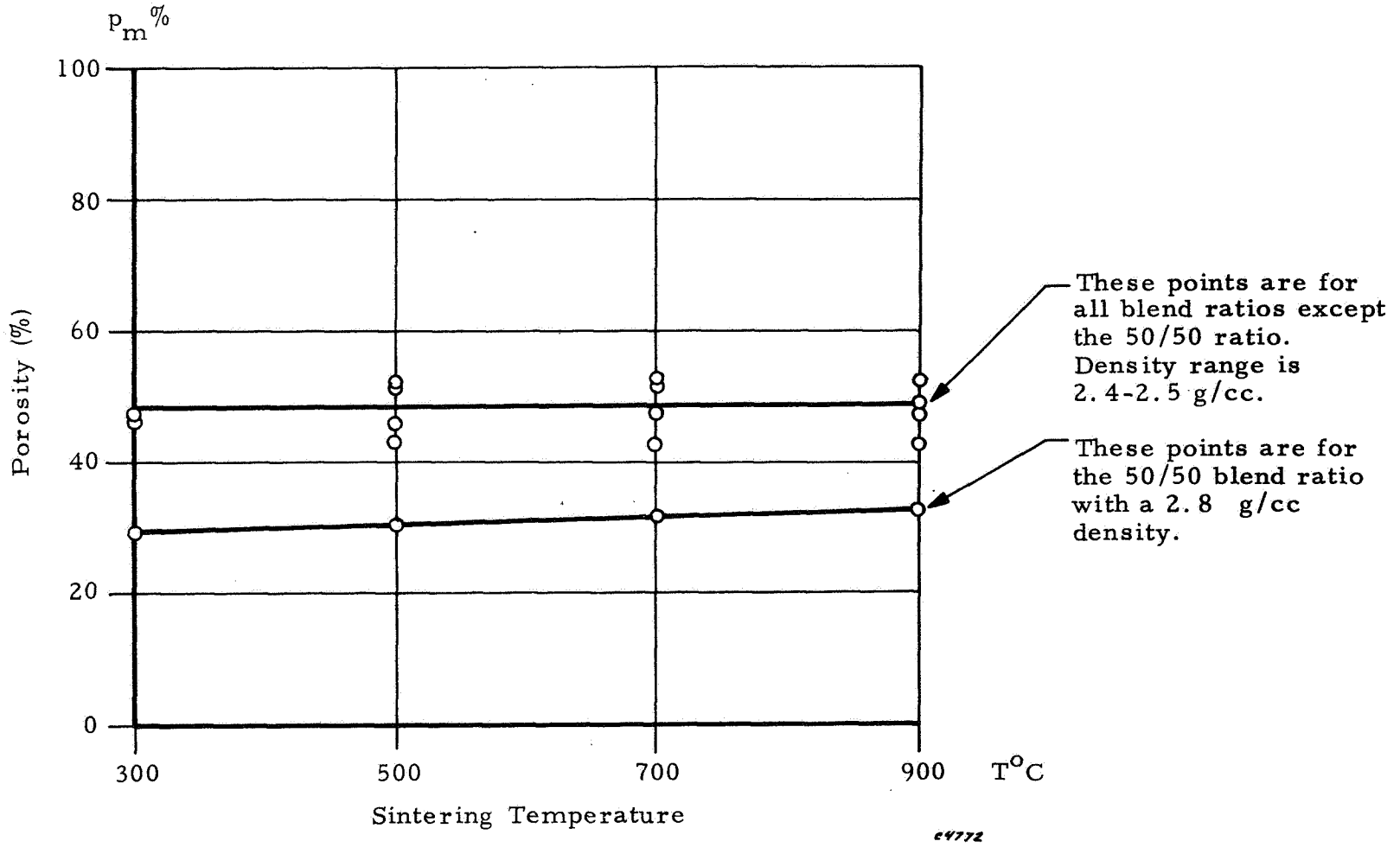


Figure 2. OL-Blends, Measured Porosity vs Sintering Temperature

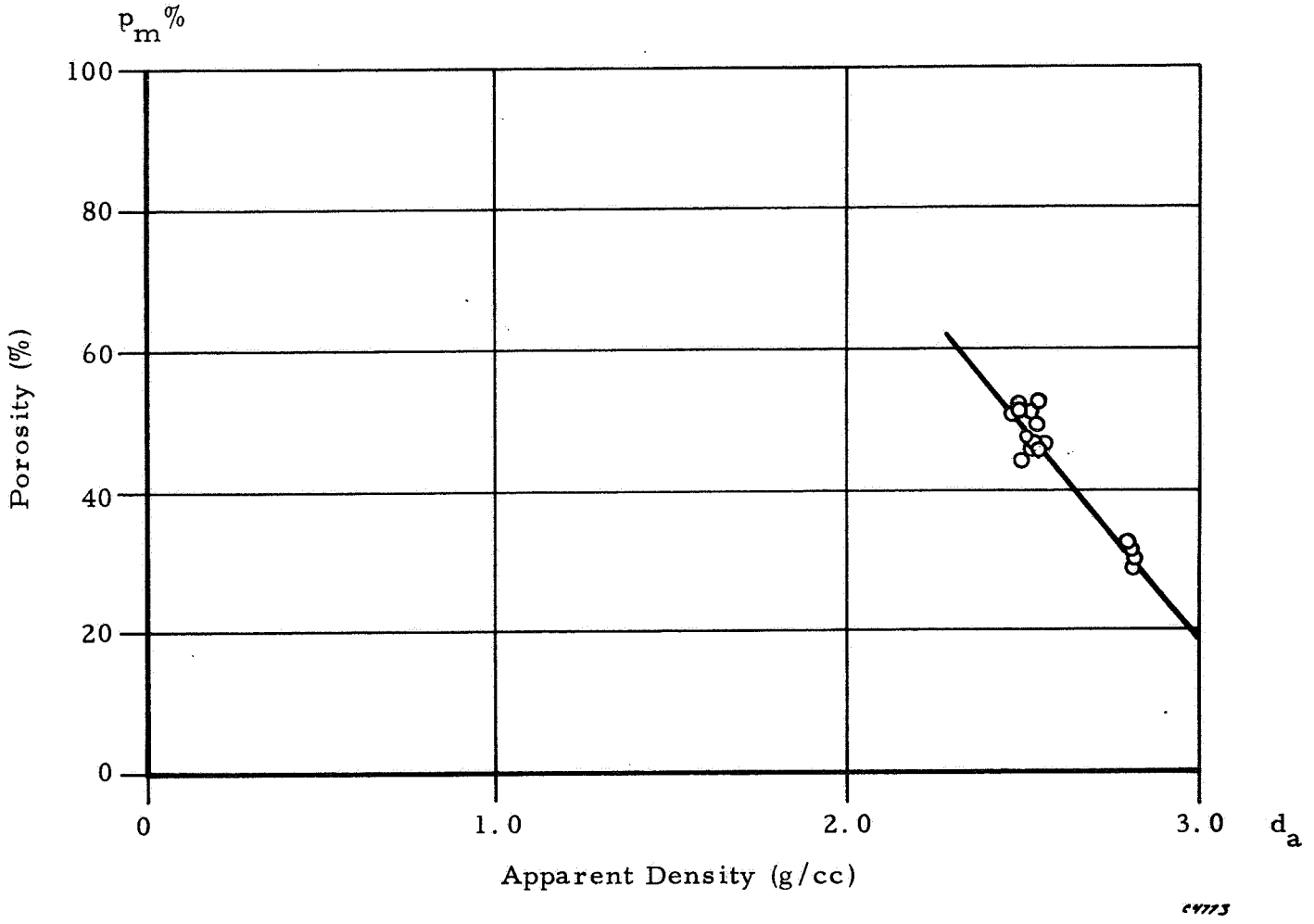


Figure 3. OL-Blends, Measured Porosity vs Apparent Density, Sintering Range 500-900°C

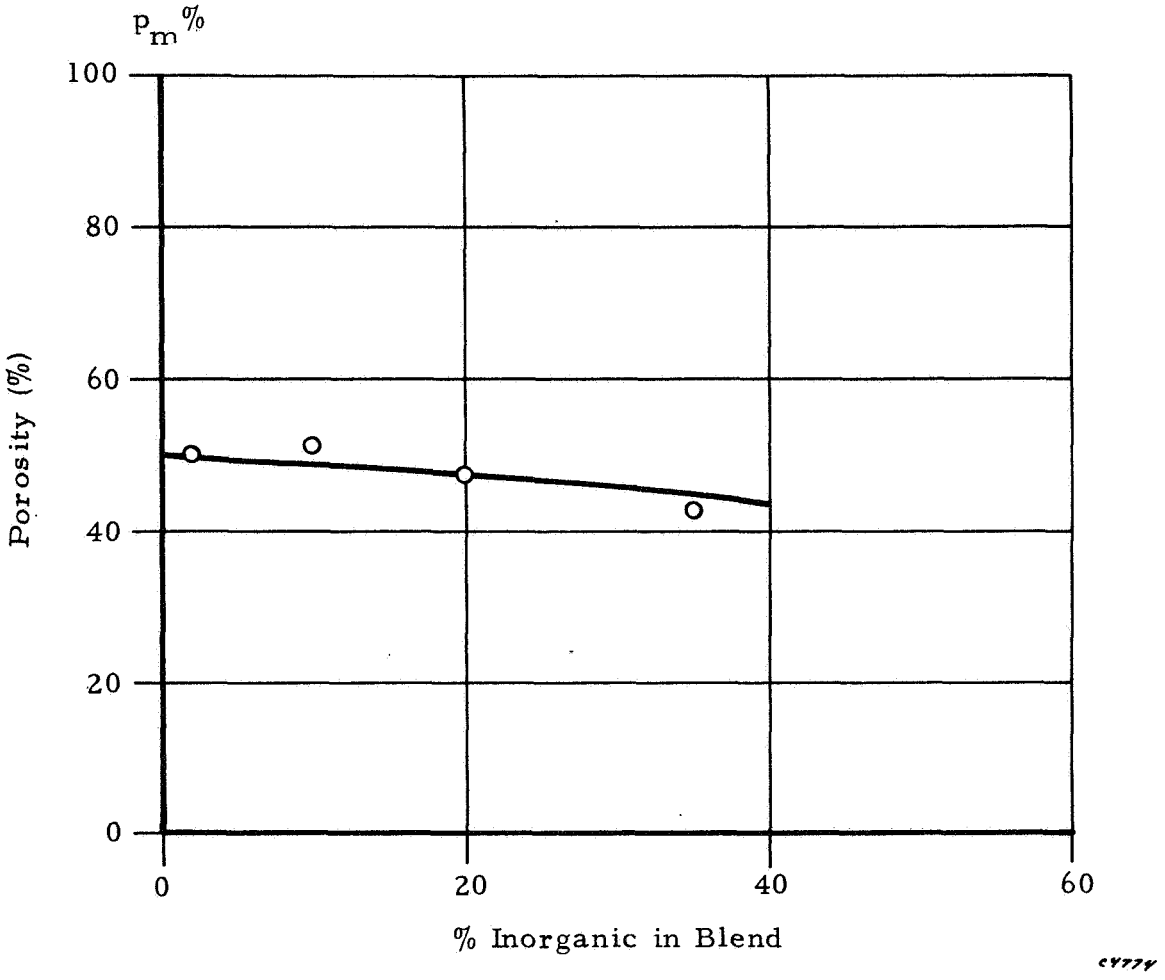


Figure 4. OL-Blends, Measured Porosity vs % Inorganic in Blend Sintered at 700°C with 2.5 g/cc Density

TABLE III

D_o = 1" PELLET PHYSICAL CHARACTERISTICS I

Material: Z

$\Delta m = m' - m$

$$\text{weight loss \%} = \frac{m_o - m}{m_o} \times 100$$

Material	Ratio	Temp. °C	Before Sintering			After Sintering						
			N_o (mils)	V_o (c.c.)	m_o (g)	D (in.)	N (mils)	V (c.c.)	$m_{(g)}$ (dry)	$m'_{(g)}$ (wet)	Δm (g)	Weight Loss %
Z	98/2	300	49.0	0.630	1.590	1	49.0	0.630	1.545	disintegrated		2.8
		500	49.0	0.630	1.596	1	49.0	0.630	1.548	1.892	0.344	3.0
		700	50.0	0.643	1.594	1	50.0	0.643	1.547	1.887	0.340	3.0
		900	50.0	0.643	1.594	1	50.0	0.643	1.547	1.896	0.349	3.0
	90/10	300	49.5	0.637	1.600	1	50.0	0.643	1.558	disintegrated		2.6
		500	51.0	0.656	1.616	1	51.0	0.656	1.572	1.909	0.337	2.7
		700	51.0	0.656	1.598	1	51.0	0.656	1.553	1.917	0.364	2.8
		900	50.5	0.650	1.597	1	51.0	0.656	1.552	1.914	0.362	2.8
	80/20	300	49.5	0.637	1.606	1	49.5	0.637	1.569	disintegrated		2.3
		500	49.5	0.637	1.601	1	49.5	0.637	1.565	1.903	0.338	2.2
		700	49.5	0.637	1.597	1	46.5	0.598	1.559	1.858	0.299	2.4
		900	49.5	0.637	1.602	1	49.0	0.630	1.563	1.904	0.341	2.4
	65/35	300	50.5	0.650	2.275	1	50.0	0.643	2.225	2.434	0.209	2.2
		500	49.0	0.630	2.275	1	49.0	0.630	2.221	2.430	0.209	2.4
		700	49.5	0.637	2.276	1	49.5	0.637	2.217	2.429	0.212	2.6
		900	50.0	0.643	2.276	1	49.5	0.637	2.213	2.428	0.215	2.8
	50/50	300	49.5	0.637	1.613	1	49.0	0.630	1.572	disintegrated		2.5
		500	48.0	0.617	1.604	1	47.5	0.611	1.557	1.862	0.305	2.9
		700	50.5	0.650	1.606	1	50.0	0.643	1.560	1.887	0.327	2.9
		900	47.5	0.611	1.595	1	47.0	0.605	1.548	1.850	0.302	2.9

$a = \frac{\Delta m}{m} \times 100$

$d_a = \frac{m}{V}$

$p_m = a \cdot d_a$

$p = \frac{d_c - d_a}{d_c} \times 100$

$\Delta p \equiv p - p_m$

$\sigma = \frac{V_o - V}{V_o} \times 100$

TABLE IV

D_o = 1" PELLETS PHYSICAL CHARACTERISTICS II

Material: Z

Material	Ratio	Temp. °C	a%	d_a (g/cc)	p_m%	d_c (g/cc)	p%	Δp%	σ %
Z	98/2	300	—	—	—	5.47	—		Disintegrated
		500	22.2	2.46	54.6	5.47	55.1	0.5	0
		700	22.0	2.41	52.9	5.47	56.0	3.1	0
		900	22.6	2.41	54.3	5.47	56.0	1.7	0
	90/10	300	—	—	—	5.47	—	—	Disintegrated
		500	21.4	2.40	51.4	5.47	56.2	4.8	0
		700	23.4	2.37	55.5	5.47	56.7	1.2	0
		900	23.3	2.37	55.2	5.47	56.7	1.5	0
	80/20	300	—	—	—	5.47	—	—	Disintegrated
		500	21.6	2.47	53.1	5.47	55.1	2.0	0
		700	19.2	2.61	50.0	5.47	52.3	2.3	2.3
		900	21.8	2.48	54.1	5.47	54.6	0.5	1.1
	65/35	300	9.4	3.46	32.5	5.48	36.9	4.4	1.1
		500	9.4	3.52	33.2	5.48	35.7	2.5	0
		700	9.6	3.48	33.3	5.48	36.5	3.2	0
		900	9.7	3.47	33.8	5.48	36.6	2.8	0.9
	50/50	300	—	—	—	5.48	—	—	Disintegrated
		500	19.6	2.55	49.9	5.48	53.5	3.6	1.0
		700	21.0	2.43	50.9	5.48	55.7	4.9	1.1
		900	19.5	2.56	49.9	5.48	53.3	3.4	1.0

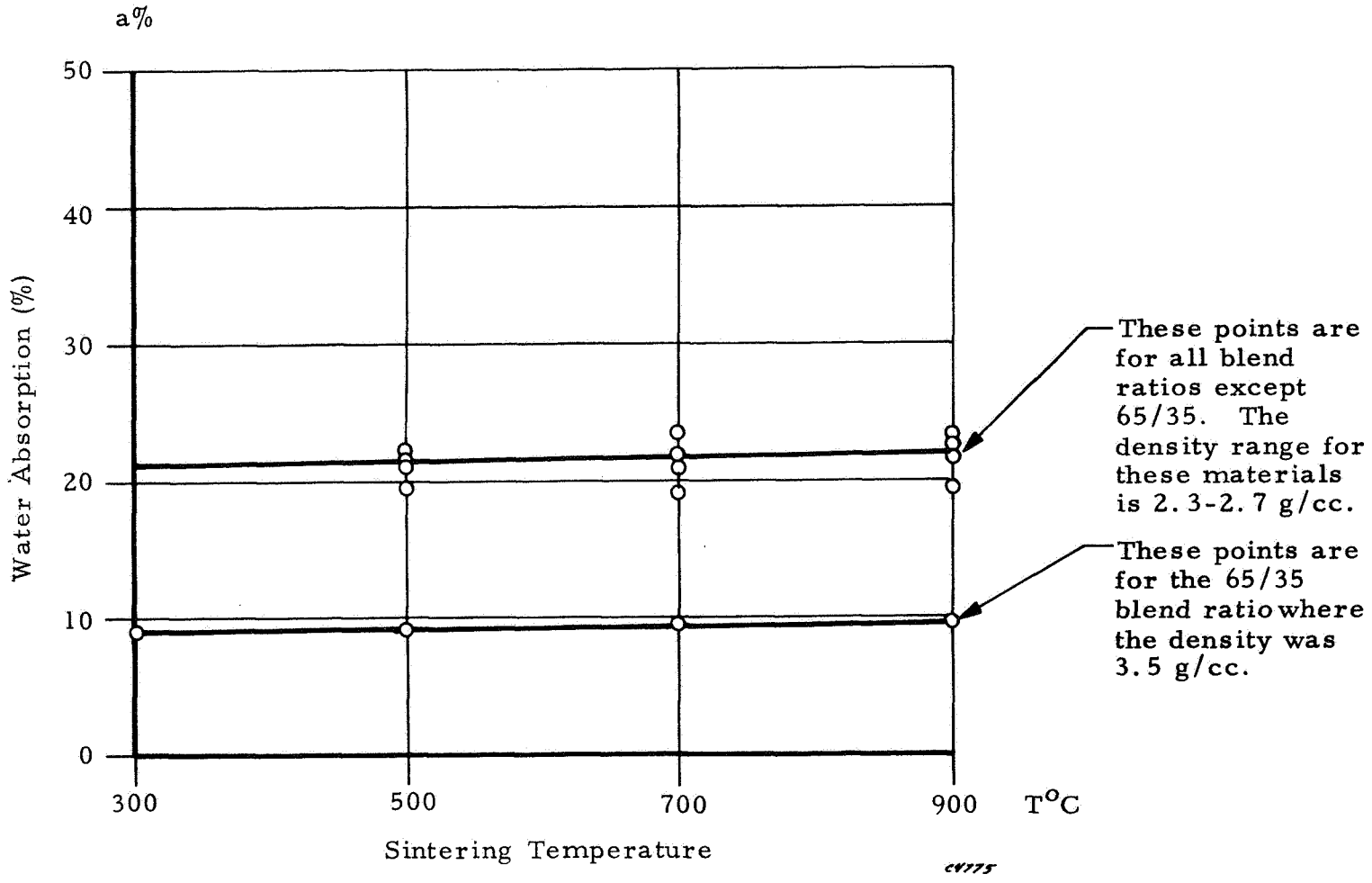


Figure 5. Z-Blends, Absorption vs Sintering Temperature

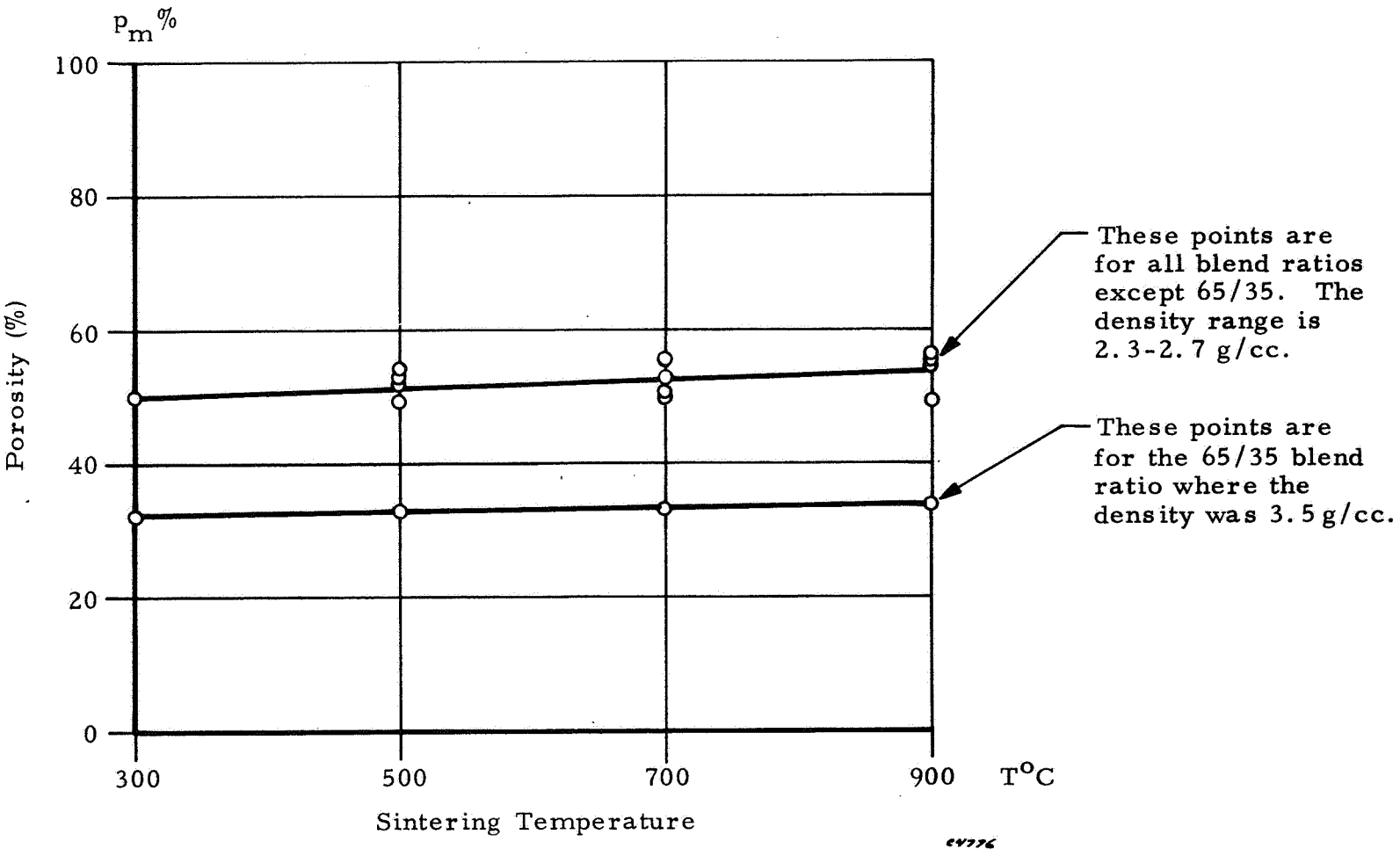


Figure 6. Z-Blends, Measured Porosity vs Sintering Temperature

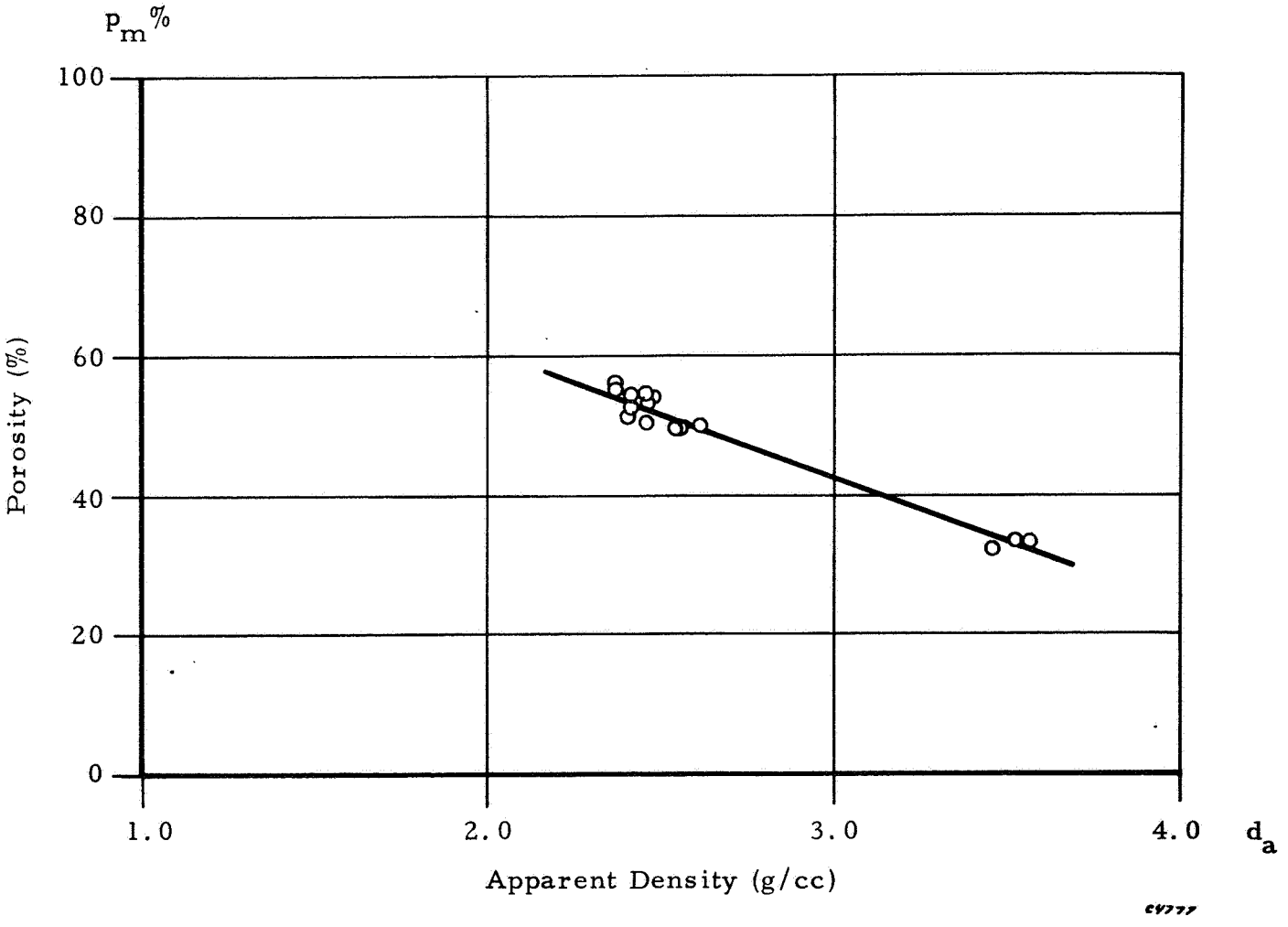


Figure 7. Z-Blends, Measured Porosity vs Apparent Density, Sintering Range 500-900°C

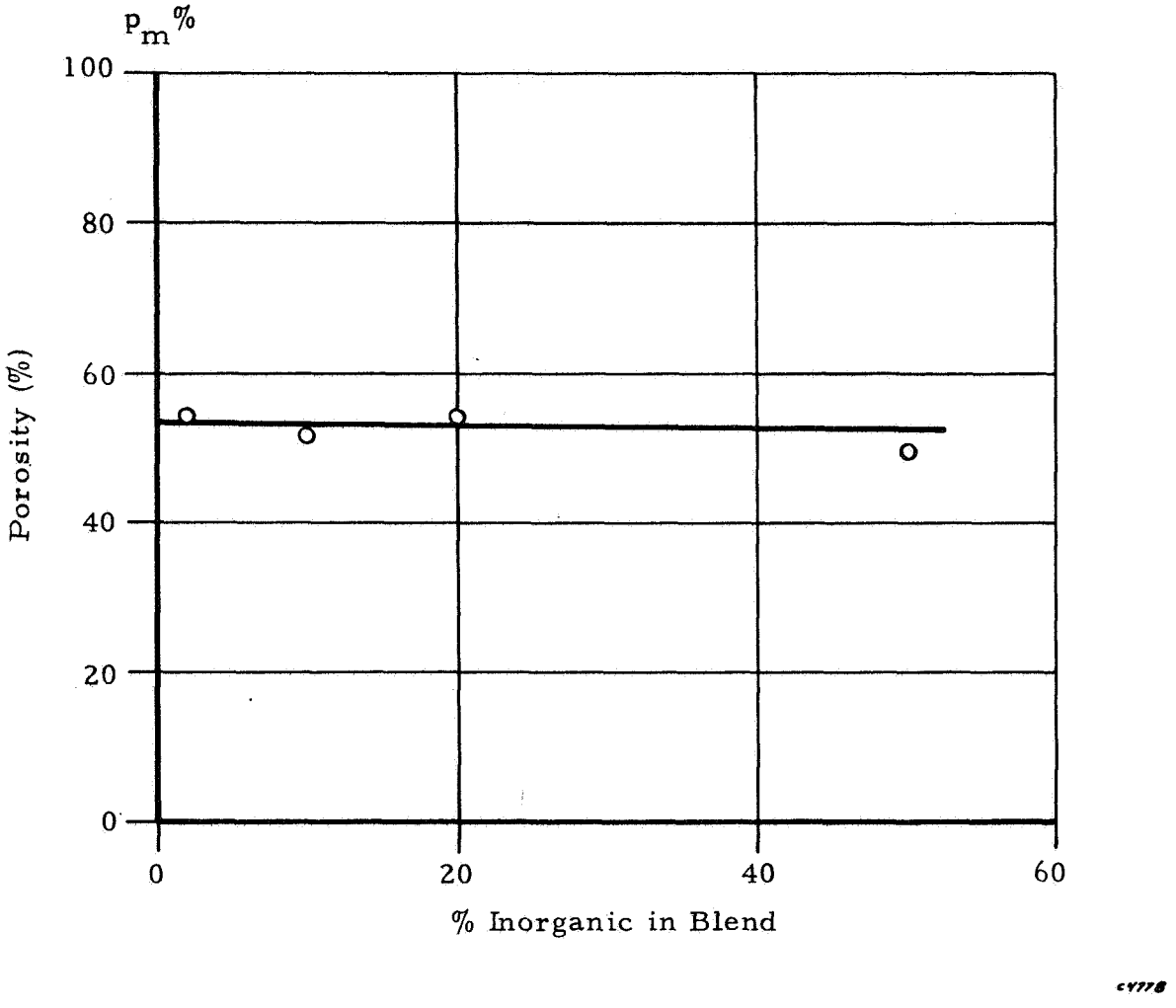


Figure 8. Z-Blends, Measured Porosity vs % Inorganic in Blend – Sintered at 700°C with 2.5 g/cc Density

TABLE V

D_o = 1" PELLET PHYSICAL CHARACTERISTICS I

Material: M

$\Delta m = m' - m$

$$\text{weight loss \%} = \frac{m_o - m}{m_o} \times 100$$

Material	Ratio	Temp. °C	Before Sintering			After Sintering						
			N_o (mils)	V_o (c.c)	m_o (g)	D (in.)	N (mils)	V (c.c.)	$m_{(g)}$ (dry)	$m'_{(g)}$ (wet)	Δm (g)	Weight Loss %
M	98/2	300	49.0	0.630	1.607	1	48.0	0.617	1.572	disintegrated		2.2
		500	49.0	0.630	1.615	1	49.0	0.630	1.570	1.899	0.329	2.8
		700	50.0	0.643	1.610	1	48.0	0.617	1.563	1.903	0.340	2.9
		900	50.0	0.643	1.603	1	49.0	0.630	1.553	1.900	0.347	3.1
	90/10	300	48.5	0.624	1.598	1	49.0	0.630	1.574	disintegrated		1.5
		500	49.0	0.630	1.596	1	49.0	0.630	1.522	disintegrated		4.6
		700	49.5	0.637	1.599	1	48.0	0.617	1.507	1.846	0.339	5.8
		900	48.5	0.624	1.597	1	48.0	0.617	1.546	1.827	0.281	3.2
	80/20	300	48.5	0.624	1,593	1	48.5	0.624	1.487	1.750	0.263	6.7
		500	49.8	0.641	1.648	1	49.5	0.637	1.510	1.836	0.326	8.4
		700	49.8	0.641	1.623	1	49.5	0.637	1.459	1.799	0.340	10.1
		900	49.7	0.639	1.628	1	49.2	0.633	1.456	1.792	0.336	10.6
	65/35	300	50.5	0.650	1.750	1	50.5	0.650	1.683	1.888	0.205	3.8
		500	50	0.643	1.744	1	50.0	0.643	1.565	1.859	0.294	10.3
		700	51.0	0.656	1.749	1	49.0	0.630	1.549	1.835	0.286	11.4
		900	50.0	0.643	1.744	1	50.0	0.643	1.533	1.818	0.285	12.1
	50/50	300	51.5	0.662	1.503	1	51.5	0.662	1.453	1.653	0.200	3.3
		500	51.5	0.662	1.507	0.997	50.5	0.646	1.273	1.595	0.322	15.5
		700	51.0	0.656	1.508	1	50.5	0.650	1.241	1.572	0.331	17.1
		900	51.0	0.656	1.504	0.982	50.0	0.620	1.216	1.545	0.329	19.1

$$a = \frac{\Delta m}{m} \times 100$$

$$d_a = \frac{m}{V}$$

$$p_m = a \cdot d_a$$

TABLE VI

D_o = 1" PELLETS PHYSICAL CHARACTERISTICS II

Material: M

$$p = \frac{d_c - d_a}{d_c} \times 100$$

$$\Delta p = p - p_m$$

$$\sigma = \frac{V_o - V}{V_o} \times 100$$

Material	Ratio	Temp. °C	a%	d_a (g/cc)	p_m%	d_c (g/cc)	p%	Δp%	σ%
M	98/2	300	–	–	–	5.41	–	–	Disintegrated
		500	21.0	2.49	52.2	5.41	53.9	1.7	0
		700	21.8	2.53	55.1	5.41	53.2	1.9	4.0
		900	22.3	2.47	55.1	5.41	55.1	0	2.0
	90/10	300	–	–	–	5.20	–	–	Disintegrated
		500	–	–	–	5.20	–	–	Disintegrated
		700	22.5	2.44	54.9	5.20	54.9	0	3.1
		900	18.2	2.51	45.5	5.20	51.8	6.3	1.1
	80/20	300	17.7	2.38	42.1	4.95	51.9	9.8	0
		500	21.6	2.37	51.2	4.95	52.1	0.9	0.6
		700	23.3	2.29	53.4	4.95	53.7	0.3	0.6
		900	23.1	2.30	53.1	4.95	53.5	0.4	0.9
	65/35	300	12.2	2.59	31.5	4.62	44.0	12.5	0
		500	18.8	2.43	45.7	4.62	47.3	1.6	0
		700	18.5	2.46	45.4	4.62	46.8	1.4	4.0
		900	18.6	2.38	44.3	4.62	48.4	4.1	0
	50/50	300	13.8	2.19	30.2	4.33	49.3	19.1	0
		500	25.3	1.97	49.8	4.33	54.5	4.7	2.4
		700	26.7	1.91	50.9	4.33	55.9	5.0	0.9
		900	27.1	1.96	53.1	4.33	54.7	1.6	5.5

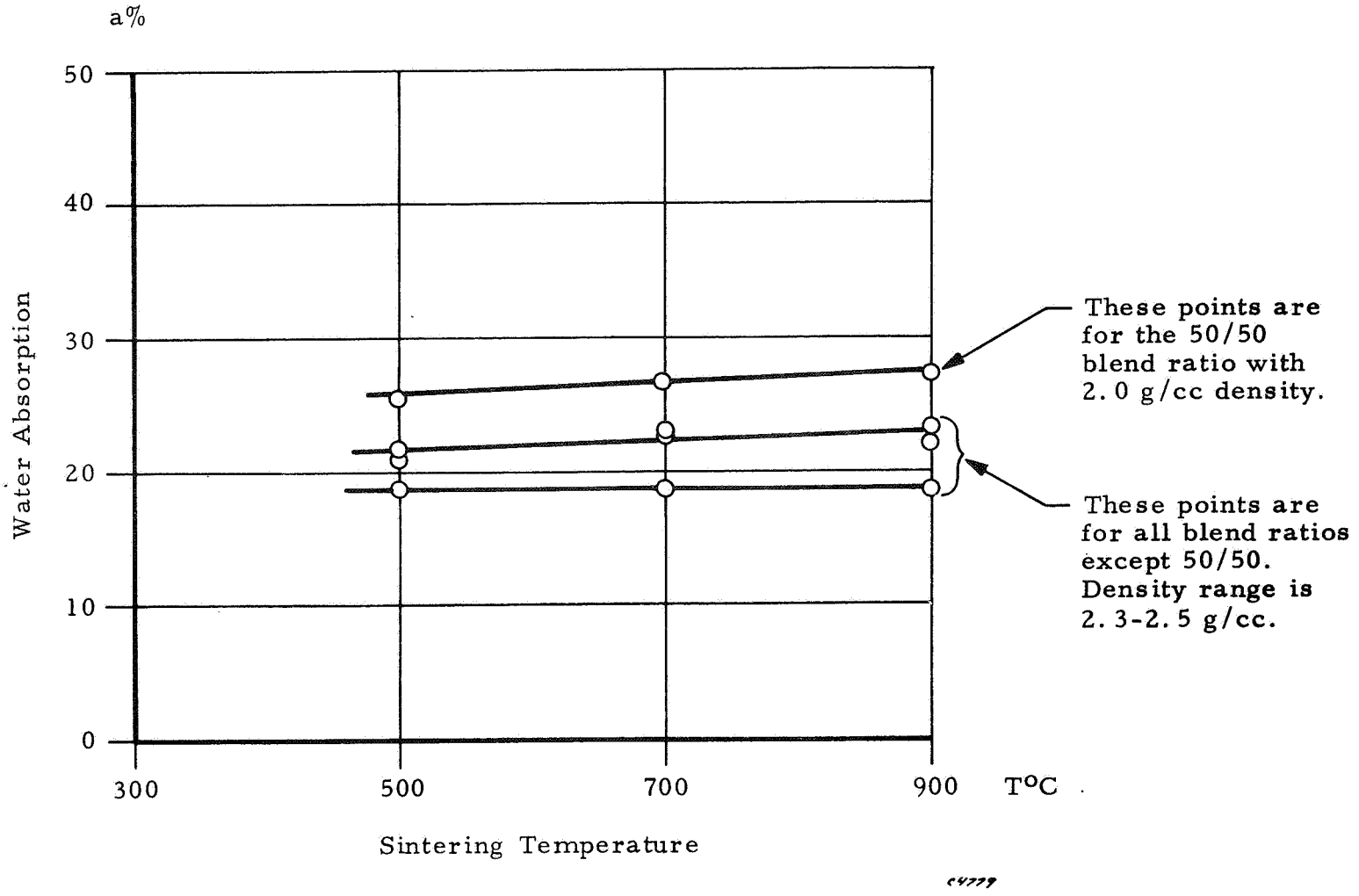


Figure 9. M-Blends, Absorption vs Sintering Temperature

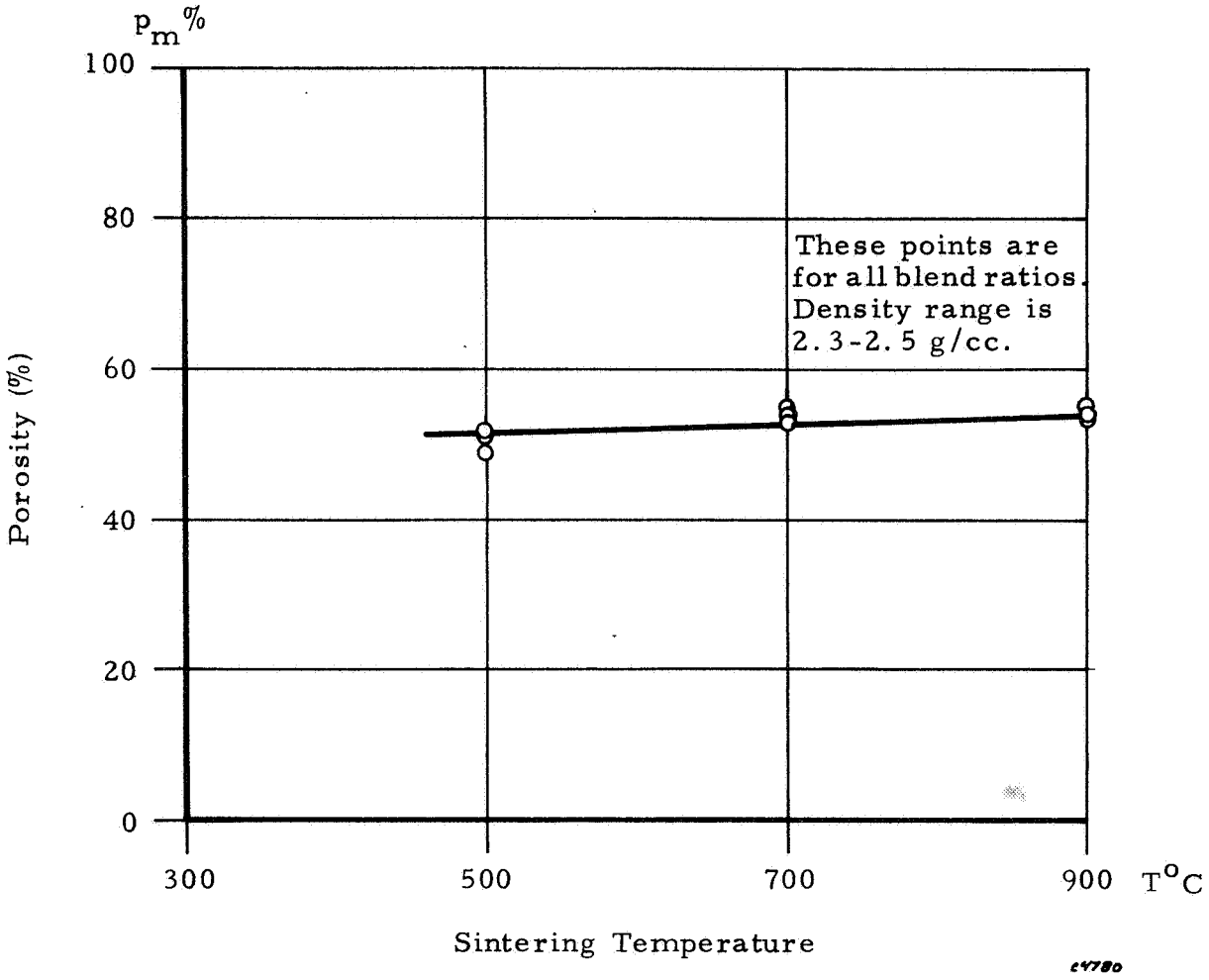


Figure 10. M-Blends, Measured Porosity vs Sintering Temperature

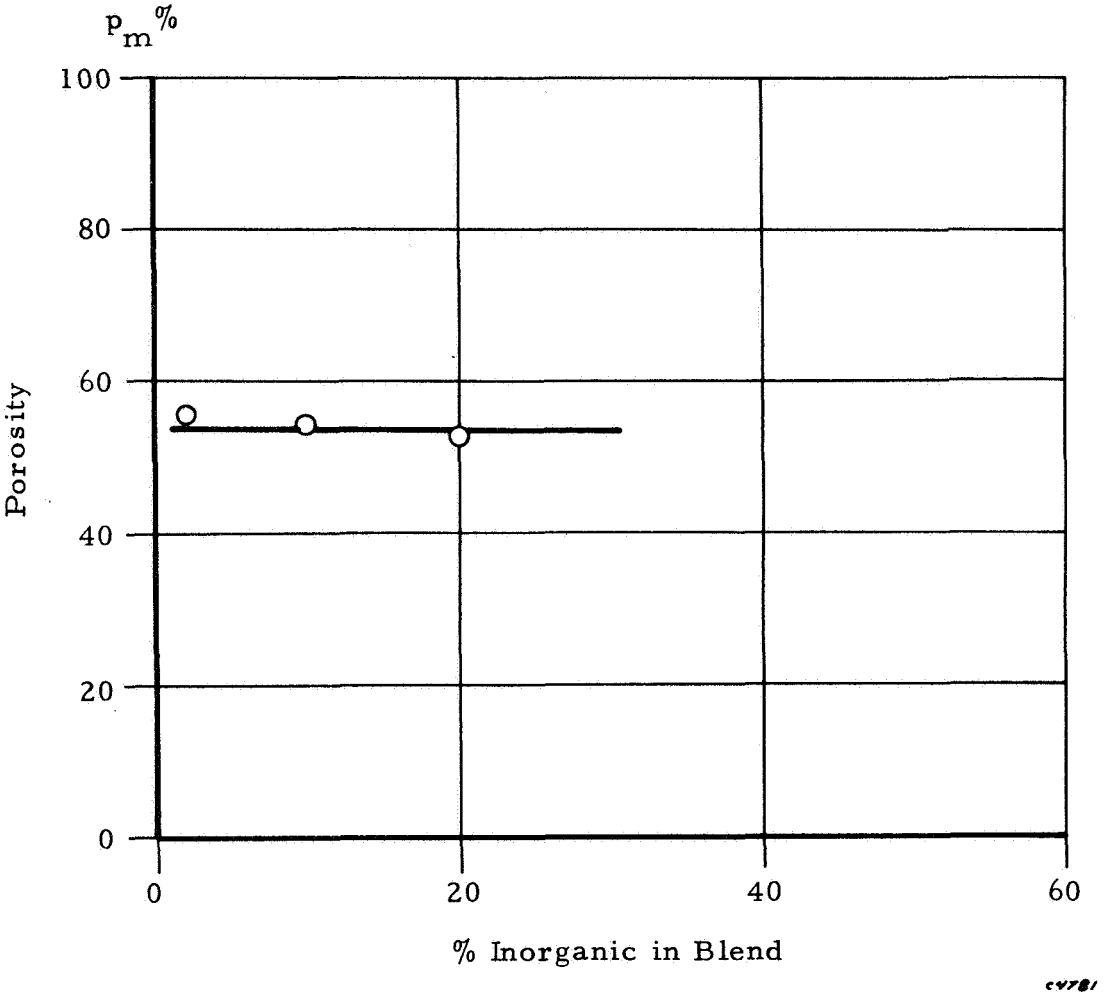


Figure 11. M-Blends, Measured Porosity vs % Inorganic in Blend-Sintered at 700°C with 2.3-2.5 g/cc Density

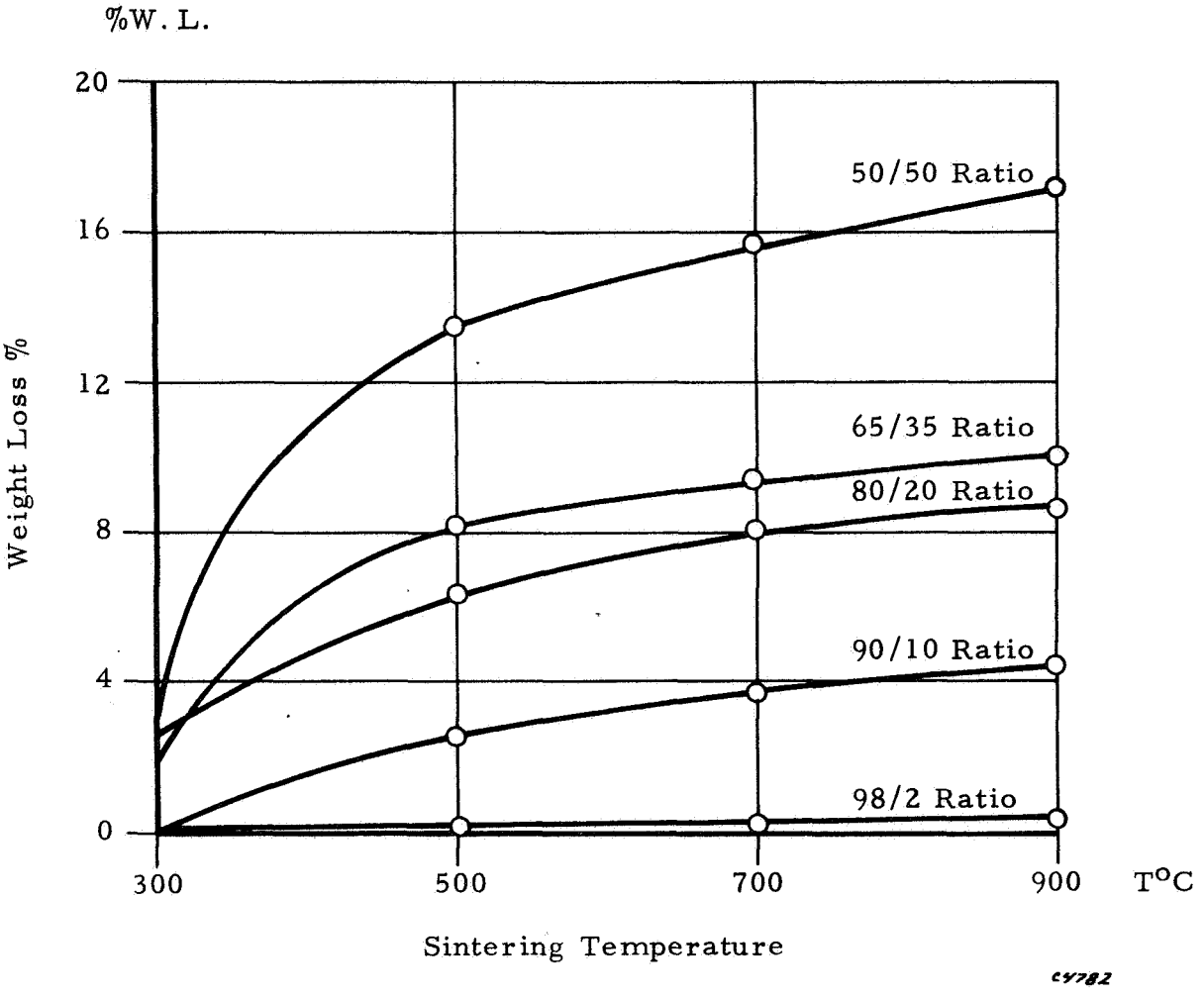


Figure 12. M-Blends, Weight Loss vs Sintering Temperature

TABLE VII

D_o = 1" PELLET PHYSICAL CHARACTERISTICS I

Material: ZnO

$\Delta m = m' - m$

$$\text{weight loss \%} = \frac{m_o - m}{m_o} \times 100$$

Material	Ratio	Temp. °C	Before Sintering			After Sintering						
			N_o (mils)	V_o (c.c.)	m_o (g)	D (in.)	N (mils)	V (c.c)	$m_{(g)}$ (dry)	$m'_{(g)}$ (wet)	Δm (g)	Weight Loss %
ZnO	100/0	300	50.0	0.643	1.596	1	50.0	0.643	1.579	disintegrated		1.1
		500	50.0	0.643	1.594	1	50.0	0.643	1.578	1.929	0.351	1.0
		700	50.0	0.643	1.598	1	50.0	0.643	1.579	1.934	0.355	1.2
		900	49.0	0.630	1.597	1	48.0	0.617	1.575	1.904	0.329	1.4

$$a = \frac{\Delta m}{m} \times 100$$

$$d_a = \frac{m}{V}$$

$$p_m = a \cdot d_a$$

TABLE VIII

D_o = 1" PELLETS PHYSICAL CHARACTERISTICS II

Material: ZnO

$$p = \frac{d_c - d_a}{d_c} \times 100$$

$$\Delta p = p - p_m$$

$$\sigma = \frac{V_o - V}{V_o} \times 100$$

Material	Ratio	Temp. °C	a%	d_a (g/cc)	p_m%	d_c (g/cc)	p%	Δ p%	σ %
ZnO	100/0	300	—	—	—	5.47	—	—	Disintegrated
		500	22.2	2.45	54.6	5.47	55.1	0.5	0
		700	22.5	2.46	55.2	5.47	55.2	0	0
		900	20.9	2.55	53.3	5.47	53.3	0	2.1

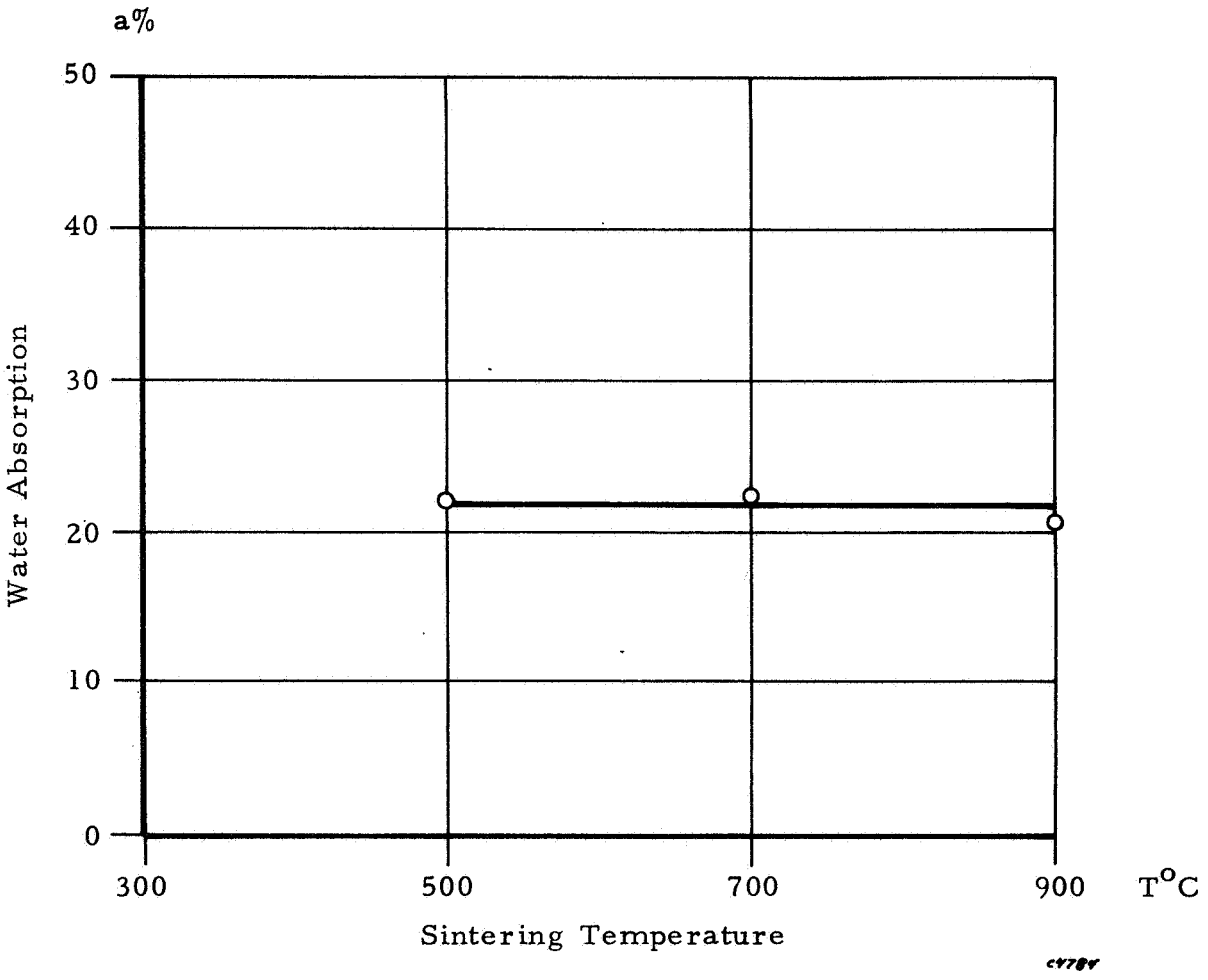


Figure 13. 100% ZnO, Absorption vs Sintering Temperature

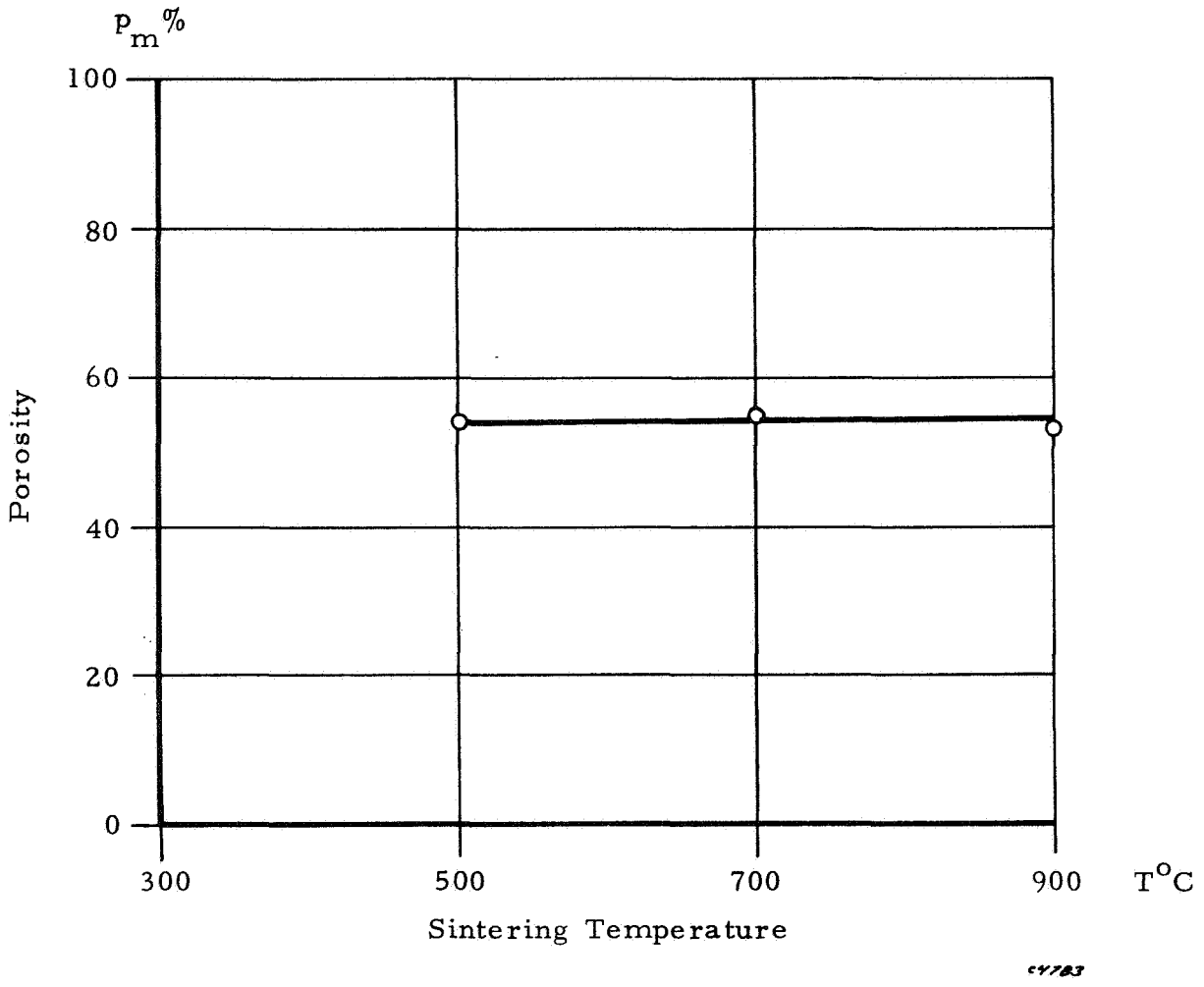


Figure 14. 100% ZnO, Measured Porosity vs Sintering Temperature

TABLE IX

WEIGHT LOSS OF PELLETS WITH MAGNESIA

μ = fraction of Magnesia in the original mix before sintering.
The calculated weight loss percentage is then:

$$W.L.\ \% = \frac{18\mu}{40.3 + 18\mu} \times 100$$

Weight Loss

Magnesia Fraction	Calculated	Experimental	
		Total	Corrected for Organic Loss
0.50	18.3%	19.1%	17.1
0.35	13.4	12.1	10.1
0.20	8.3	10.6	8.6
0.10	4.3	5.8	3.8
0.02	0.9	3.1	1.1

TABLE X

TRUE DENSITY

If ζ is the fraction of ZnO (true density 5.47) in a mix of ZnO and inorganic material of true density d_i, the true density of the composite mix d_c is related to the other densities by the formula:

$$\frac{1}{d_c} = \frac{\zeta}{5.47} + \frac{1 - \zeta}{d_i}$$

The following table gives all composite densities for the selected materials and rations to be investigated.

	Ratio	98/2	95/5	90/10	80/20	65/35	50/50
Material	OL (d_i = 3.3)	5.40	5.30	5.13	4.83	4.45	4.12
	Z (d_i = 5.49)	5.47	5.47	5.47	5.47	5.48	5.48
	M (d_i = 3.58)	5.41	5.33	5.20	4.95	4.62	4.33

The calculated porosities p% are slightly higher than the measured porosities p_m% in the temperature range of 500° to 900°C. The difference Δp is probably due to experimental errors rather than to the contribution of pores inaccessible to liquid.

On the basis of the limited test data generated at this point, optimum criteria to look for are (not necessarily in order of priority):

Strength of the electrode

A range of approximately 50% porosity

No closed pores

No weight loss (This condition not fulfilled by Magnesia militates against its choice because of the instability of the matrix structure in the electrolyte medium.)

Other constraints were added as higher sintering temperatures were investigated.

Higher Temperature Range

The second range of temperature is defined as over 900°C up to 1400°C. It was soon established that, as expected, the physical properties would be very much dependent on the sintering temperature, particularly beyond 1000°C. The absorption and porosity drop sharply (Figure 15) due to the excessive shrinkage (Figure 16). Consequently, the physical measurements on the 1" diameter pellets were limited to two selected materials, OL and Z, using selected ratios of ZnO and inorganic and a range of sintering temperature from 800°C to 1200°C for continuity purposes. Tables XI and XII give all pertinent data. Included is a set of data regarding pure ZnO submitted to the same process and sintering temperature for reference purposes.

Although the actual zinc oxide mix electrode will not be sintered at over 900°C, it may be useful to sinter the mix itself at higher temperatures with the intent of modifying the binding of zinc oxide particles with inorganic material particles. Blends sintered at temperatures of 1000°C, 1200°C, and 1400°C respectively were compared with the same blends of powders sintered separately at the same temperatures. Starting with ZnO, Z material and a blend of 80% ZnO and 20% Z, each material was sintered separately at each temperature. Then, a blend of 80% sintered ZnO and 20% sintered Z was prepared (for each sintering temperature used). The blends sintered as blends were compared with the mixes where materials were presintered then blended in the same ratio. X-ray diffraction and reflection (color) under ultraviolet light showed a more pronounced change with increased sintered temperature. It was speculated that a solid solution was formed, at

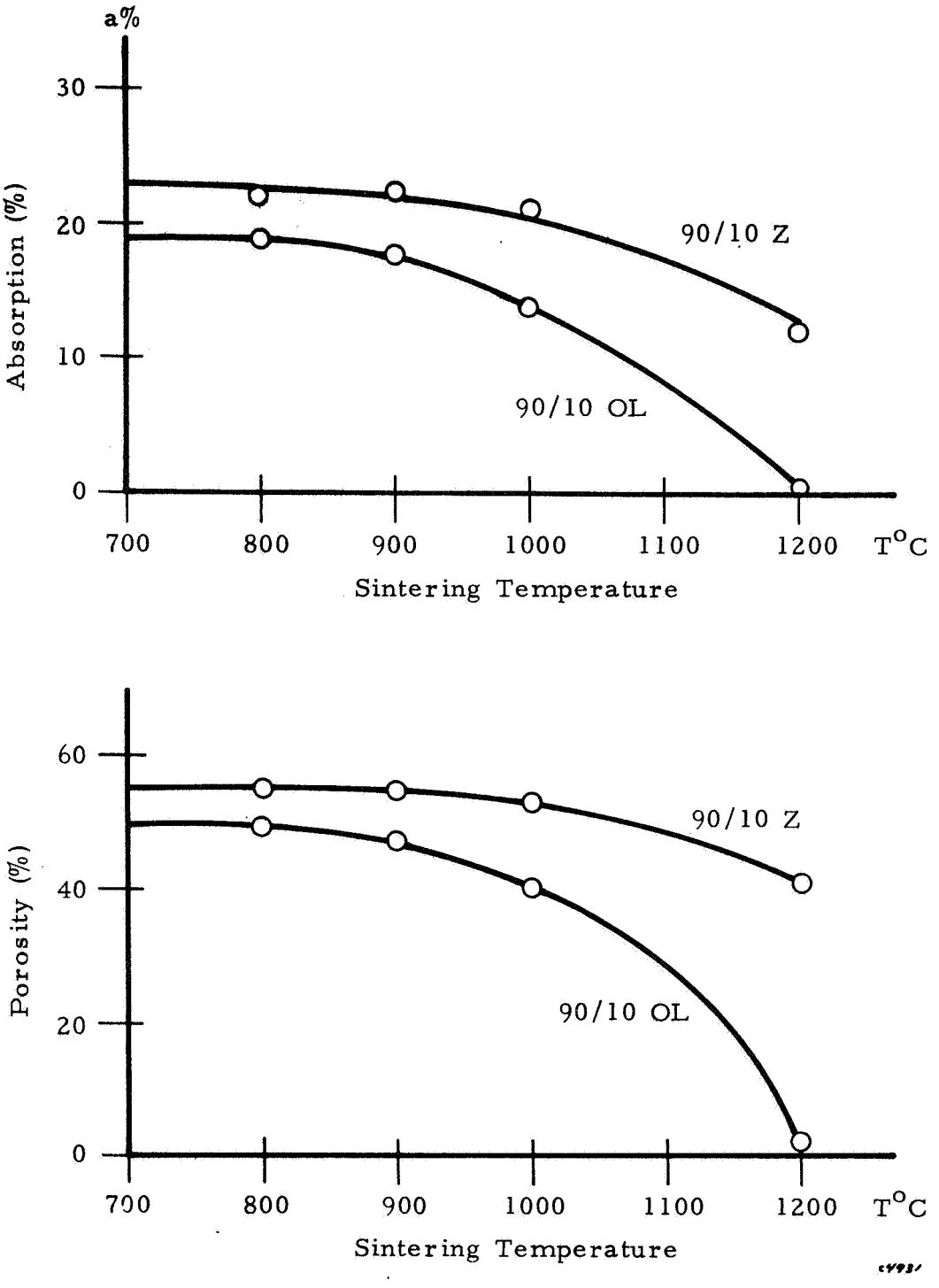


Figure 15. Absorption and Porosity vs Sintering Temperature

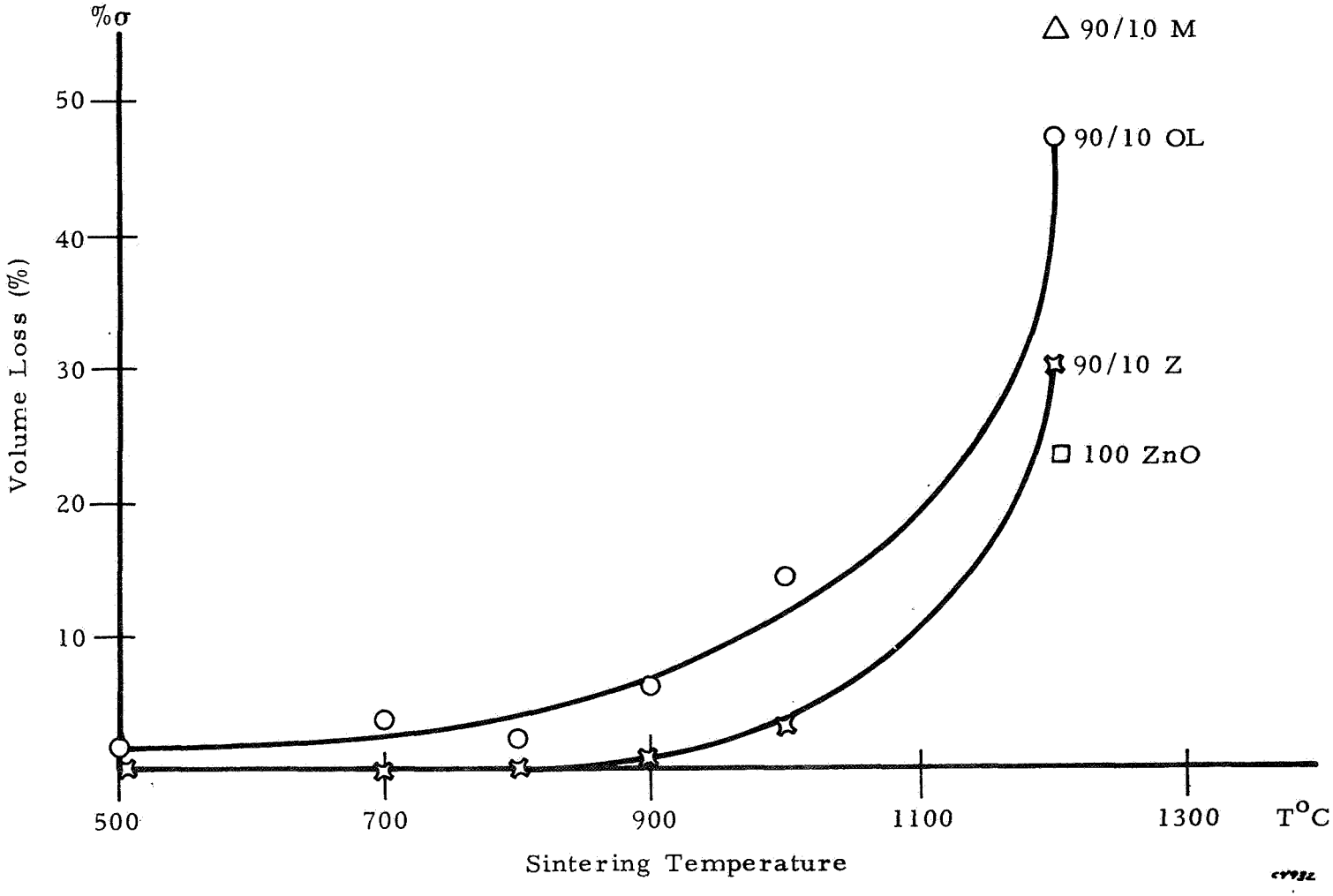


Figure 16. Volume Loss vs Sintering Temperature

TABLE XI

D_o = 1" PELLET PHYSICAL CHARACTERISTICS I (AVERAGE OF 3 PELLETS)

Material	Ratio	Temp. °C	Before Sintering			After Sintering						
			N_o (mils)	V_o (c.c.)	m_o (gm)	D (in)	N (mils)	V (c.c.)	m(gm) (dry)	m(gm) (wet)	Δm (gm)	Weight Loss %
OL	95/5	800	51.5	0.662	1.595	0.997	50.0	0.639	1.581	1.848	0.267	0.9
	90/10	800	48.0	0.617	1.580	1.000	47.0	0.605	1.551	1.849	0.298	1.8
		900	48.8	0.628	1.597	0.979	47.8	0.589	1.564	1.846	0.282	2.1
		1000	49.8	0.641	1.601	0.944	47.8	0.548	1.566	1.785	0.219	2.2
		1200	50.3	0.647	1.617	0.807	40.8	0.341	1.583	1.590	0.007	2.1
	80/20	800	49.0	0.630	1.602	1.000	49.0	0.630	1.571	1.871	0.300	1.9
		1200	50.2	0.646	1.600	0.850	42.2	0.392	1.564	1.626	0.062	2.3
	65/35	800	51.0	0.656	1.593	1.000	51.0	0.656	1.554	1.852	0.298	2.5
Z	95/5	800	51.0	0.656	1.590	1.000	51.0	0.656	1.564	1.926	0.362	1.6
	90/10	800	49.0	0.630	1.589	1.000	49.0	0.630	1.573	1.919	0.346	1.0
		900	50.5	0.650	1.601	0.996	50.5	0.644	1.565	1.919	0.354	2.2
		1000	50.3	0.647	1.600	0.988	50.0	0.628	1.567	1.899	0.332	2.1
		1200	52.8	0.679	1.612	0.894	46.5	0.478	1.577	1.773	0.196	2.2
	80/20	800	50.0	0.643	1.593	1.000	50.0	0.643	1.564	1.906	0.342	1.8
		1200	49.2	0.633	1.598	0.919	45.5	0.494	1.570	1.772	0.202	1.8
	65/35	800	50.0	0.643	1.594	1.000	50.0	0.643	1.565	1.903	0.338	1.8
M	80/20	1200	51.8	0.666	1.608	0.766	39.0	0.294	1.425	1.425	0	11.4
ZnO	100/0	1200	51.2	0.659	1.610	0.904	47.5	0.499	1.588	1.784	0.196	1.4

$\Delta m = m' - m$

$$\text{Weight Loss \%} = \frac{m_o - m}{m_o} \times 100$$

$a = \frac{\Delta m}{m} \times 100$

$a = m/V$

$p_m = a \cdot d_a$

TABLE XII

D_o = 1" PELLETS
PHYSICAL CHARACTERISTICS II
(AVERAGE OF 3 PELLETS)

$p = \frac{d_c - d_a}{d_c} \times 100$

$\Delta p = p - p_m$

$\sigma = \frac{V_o - V}{V_o} \times 100$

Material	Ratio	Temp. °C	a%	d_a (g/cc)	p_m%	d_c (g/cc)	p%	Δp%	σ%
OL	95/5	800	16.9	2.47	41.8	5.30	53.3	11.5	3.5
	90/10	800	19.2	2.56	49.3	5.13	50.0	0.7	1.9
		900	18.0	2.66	47.9	5.13	48.2	0.3	6.2
		1000	14.0	2.86	40.0	51.3	44.3	4.3	14.5
		1200	0.4	4.64	2.1	5.13	9.5	7.4	47.3
	80/20	800	19.1	2.49	47.6	4.83	48.4	0.8	0
		1200	4.0	4.00	15.8	4.83	17.4	1.6	39.3
	65/35	800	19.2	2.37	45.4	4.45	46.8	1.4	0
Z	95/5	800	23.1	2.38	55.2	5.47	56.4	1.2	0
	90/10	800	22.0	2.50	54.9	5.47	54.9	0	0
		900	22.6	2.43	55.0	5.47	55.6	0.6	0.9
		1000	21.2	2.50	52.9	5.47	54.3	1.6	2.9
		1200	12.4	3.30	41.0	5.47	41.0	0	29.6
	80/20	800	21.9	2.43	53.2	5.47	55.5	2.3	0
		1200	12.9	3.18	40.9	5.47	41.9	1.0	22.0
	65/35	800	21.6	2.43	52.6	5.48	55.6	3.0	0
M	80/20	1200	0	4.85	0	4.95	2.0	2.0	55.9
ZnO	100/0	1200	12.3	3.18	39.3	5.47	41.8	2.4	24.3

least on the surface of the particles, although a quantitative analysis could not be performed to determine the depth of that layer. The sintering time was again held constant (1 hour). It may be desirable eventually to consider a longer sintering time to establish in the electrical tests if the formation of more solid solution is beneficial.

If, therefore, the presintering of the mix helps in any way, the mix can be used in the normal procedure (addition of binders, ball milling, drying, granulating) for the fabrication of the electrode, which can then be sintered below 900°C. Pellets were made using ratios of 90/10 for OL and Z and also 100% ZnO, following the two procedures (normal and presintering). Tables XIII and XIV give their physical characteristics.

Surface Area and Pore Size Measurements

First Series

A few samples of sintered pellets were submitted to other measurements, surface area and pore size. The samples were 80/20 OL, 80/20 Z, and 80/20 M sintered at 700°C (normal process). The tests were made on three different physical samples of each material.

The specific surface area was determined by the standard BET technique using either nitrogen or krypton as the adsorbate. The results are as follows:

Sample	Surface Area (m^2/g)	Adsorbate
80/20 OL	3.32	Kr
80/20 Z	3.53	Kr
80/20 M	20.70	N

The pore size was determined by the mercury penetration method up to 50,000 psia. The pore size distribution is shown in Figures 17, 18, and 19, and in Table XV. It is worth noting that the so-called water absorption, as previously defined, corresponds to the portion of void consisting of pores over a certain dimension. The original data curves giving penetration volume in cc/g versus the pressure in psia may be found in Appendix A.

Second Series

In agreement with the NASA Program Manager, a few other combinations were selected for surface area and pore size measurements.

TABLE XIII

D_o = 1" PELLET PHYSICAL CHARACTERISTICS I (AVERAGE OF 3 PELLETS)

$$\Delta m = m' - m$$

$$\text{weight loss} = \frac{m_o - m}{m_o} \times 100$$

Material	Ratio	Temp. °C	Before Sintering			After Sintering						
			N_o (mils)	V_o (c.c.)	m_o (gm)	D (in)	N (mils)	V (c.c.)	m(gm) (dry)	m'(gm) (wet)	Δm (gm)	Weight Loss %
Normal Procedure												
OL	90/10	850	49.7	0.639	1.598	0.992	49.7	0.629	1.569	1.896	0.327	1.8
Z	90/10	850	52.5	0.675	1.605	0.992	52.0	0.668	1.589	1.986	0.379	1.0
ZnO	100/0	850	50.0	0.643	1.603	0.988	50.0	0.643	1.584	1.925	0.341	1.2
Blend Presintered at 1400°C then Normal Procedure Followed												
OL	90/10	850	52.5	0.675	1.583	0.997	52.2	0.667	1.557	1.897	0.340	1.6
Z	90/10	850	46.5	0.598	1.587	0.997	46.8	0.598	1.559	1.871	0.312	1.8
ZnO	100/0	850	47.5	0.611	1.605	0.998	47.5	0.609	1.582	1.872	0.290	1.4

$a = \frac{\Delta m}{m} \times 100$

$a = m/V$

$p_m = a \cdot d_a$

$p = \frac{d_c - d_a}{d_c} \times 100$

$\Delta p = p - p_m$

$\sigma = \frac{V_o - V}{V_o} \times 100$

TABLE XIV

D_o = 1" PELLETS PHYSICAL CHARACTERISTICS II

(Average of 3 Pellets)

Material	Ratio	Temp. °C	a%	d_a (g/cc)	p_m%	d_c (g/cc)	p%	Δp%	σ%
Normal Procedure									
OL	90/10	850	20.8	2.49	52.0	5.13	52.0	0	1.6
Z	90/10	850	23.9	2.38	56.7	5.47	56.7	0	1.0
ZnO	100/0	850	21.5	2.46	53.0	5.47	55.0	2.0	0
Blend Pre-Sintered at 1400°C Then Normal Procedure Followed									
OL	90/10	850	21.8	2.33	51.0	5.13	54.5	3.5	1.2
Z	90/10	850	20.0	2.61	52.2	5.47	52.3	0.1	0
ZnO	100/0	850	18.3	2.60	47.6	5.47	52.5	4.9	0.3

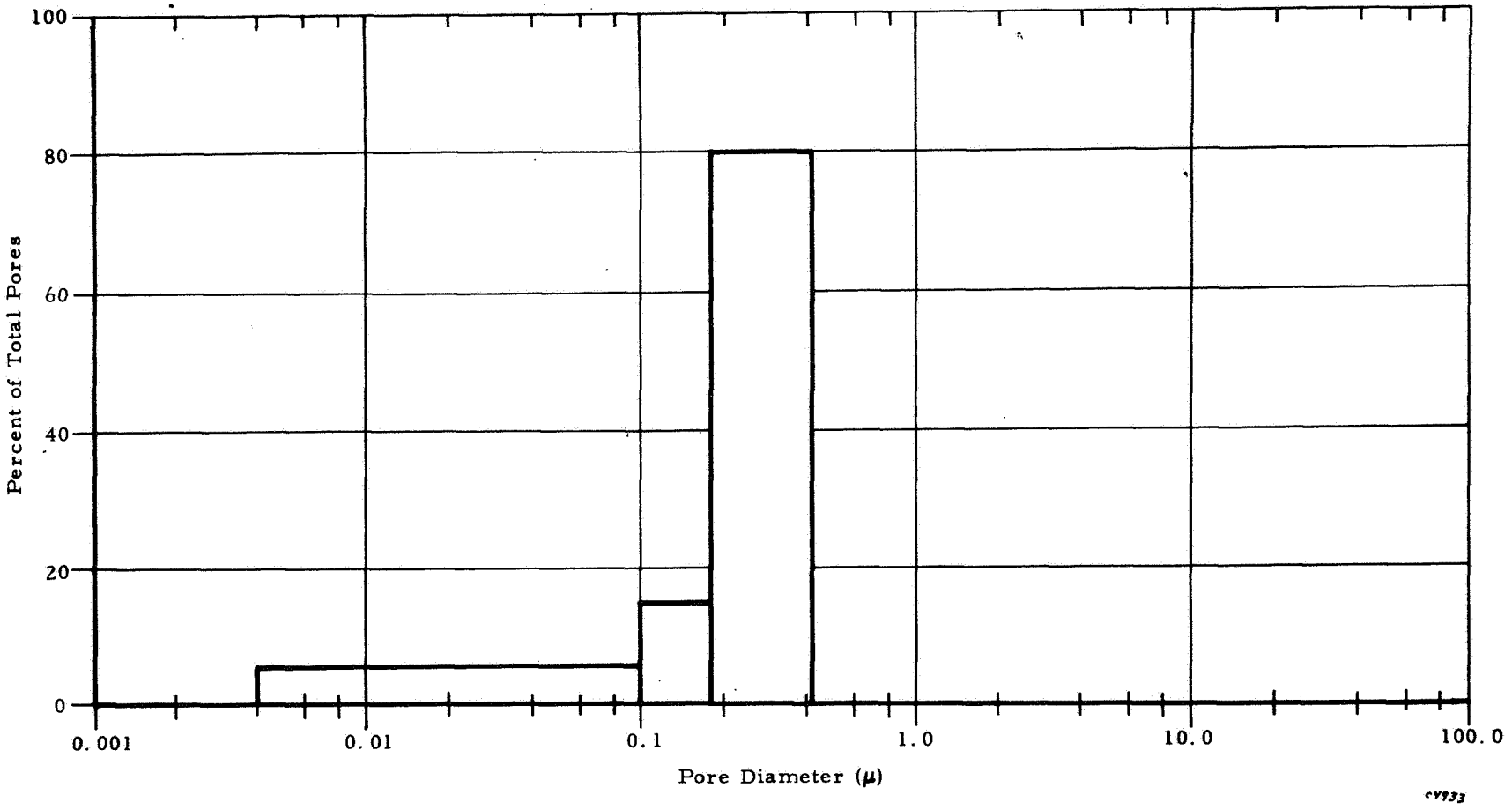


Figure 17. Pore Size Distribution of 80/20 OL Material

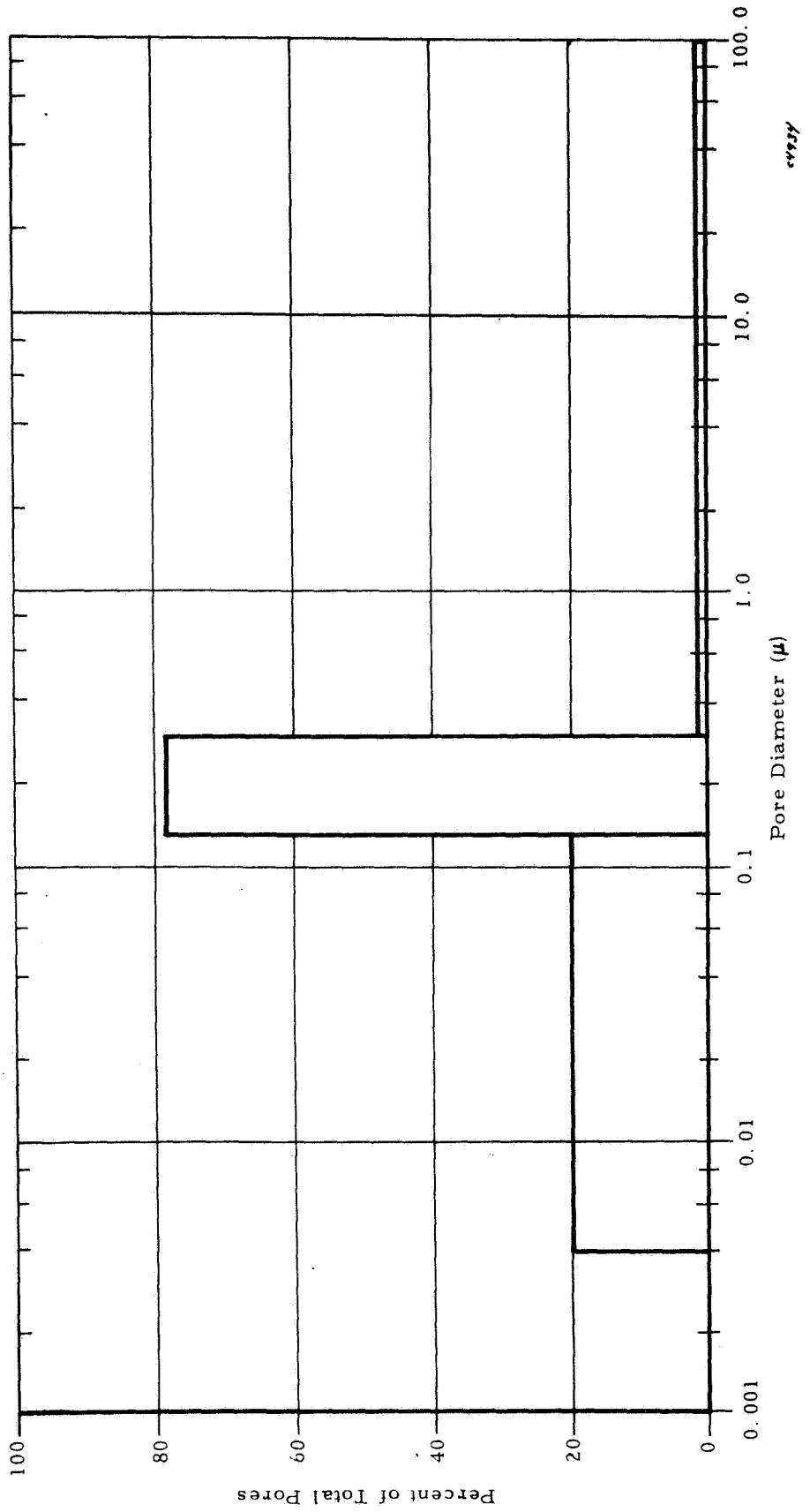


Figure 18. Pore Size Distribution of 80/20 Z Material

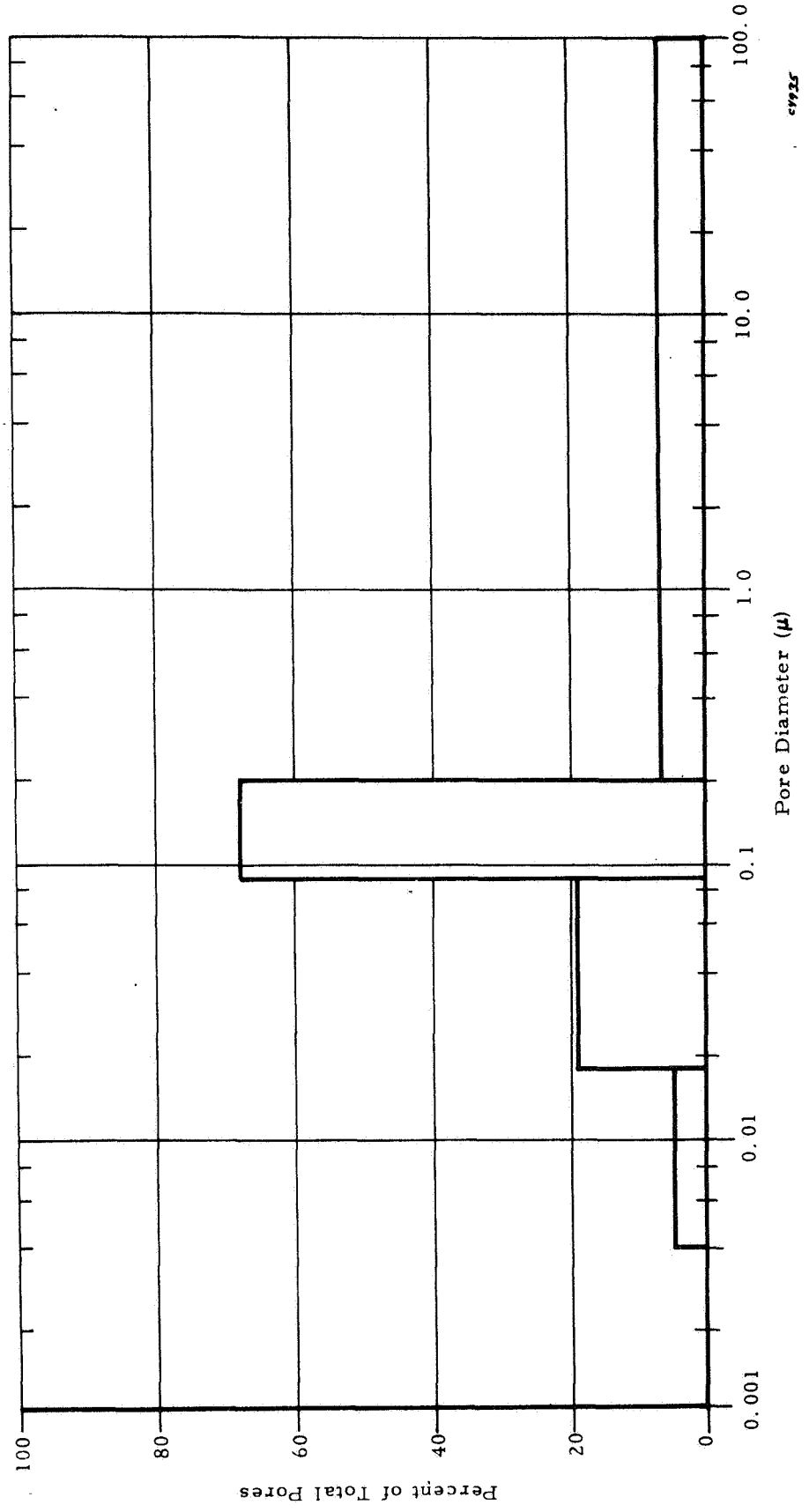


Figure 19. Pore Size Distribution of 80/20 M Material

TABLE XV

PORE SIZE DISTRIBUTION

Sample	Penetration Volume (a) ($\frac{cc}{g}$ 100) (1)	Absorption (b) ($\frac{cc}{g}$ 100) (2)	$\frac{b}{a}$ 100 (3)	Pore Diameter D (μ)	% of Total Pore Volume	
					Per Range	Cumulative
80/20 OL	17.5	14	80	D > 0.42	0	0
				0.42-0.18	80	80
				D < 0.18	20	100
80/20 Z	20.0	16	80	D > 0.29	1.5	1.5
				0.29-0.13	79	80.5
				D < 0.13	19.5	100
80/20 M	21.5	16	75	D > 0.18	7.5	7.5
				0.19-0.09	67	75
				D < 0.09	25.5	100

(1) Determined under 50,000 psia pressure.

(2) Value at the end of the linear portion of the curve of penetration vs pressure.

(3) Fraction percentage of total void volume where absorption takes place. Compare to second line of "Pore Volume, Cumulative."

The choice of combinations was restricted by the maximum number imposed by the work statement and by the elimination of the candidates least likely to be used. For instance, magnesia (material M) was not considered immediately suitable because of its excessive weight variation following wetting, drying, sintering, rewetting (hydroxide formation). Ratios of inorganic material too low or too high were temporarily set aside in order to keep a fixed medium range, chosen to be 90% ZnO and 10% inorganic, as a comparative basis. As the maximum strength of the pellets was developed at the highest sintering temperature (below 900°C), the selected temperature was fixed at 850°C. Since the two processes evolved (normal and presinter) have equal possibilities at this point, both will be considered.

This screening narrows down the choice to the following combinations:

Materials:	OL, Z
Ratio:	90/10
Sintering Temperature:	850°C
Process:	Normal (N), Presinter (PS)

Table XVI gives a summary of pore size distribution and pertinent information for all seven combinations. A few remarks are in order:

(a) It appears that the presinter process (PS) cuts down on surface area and spreads the pore distribution when compared with the normal process. It can be speculated what effect this will have on the zinc electrode performance: on one hand, the reduction of zinc exposure to electrolyte may delay its corrosion; on the other hand, reduction in electrolyte accessibility may cause premature poor performance due to dryness.

(b) The effect of higher sintering temperature is known to be shrinkage of pores which entails less electrolyte absorption. It can be seen that the percentage of pores corresponding to electrolyte absorption decreases from 93% (for the selected materials OL and Z) to 85%. However, this is not considered a problem since all pellets were originally made to the same specifications of weight, size, and thickness, starting with the same apparent density regardless of the subsequent treatment. The electrode can be originally designed so that it ends up with the desired porosity and electrolyte absorption percentages after the sintering operation.

TABLE XVI

SURFACE AREA AND PORE SIZE DISTRIBUTION

Sintering Temperature	700°C			850°C			
Ratio	80/20			90/10			
Material	OL	Z	M	OL		Z	
Process	N	N	N	N	PS	N	PS
Specific Surface Area (m^2/g)	3.32	3.53	20.7	3.85	2.28	1.82	1.63
Pore Size Range	Percentage of Pores (%)						
177 μ to 1 μ	0	0.5	3	0	2.6	3.5	3.3
1 to 0.5	0	0	1	0	3	0	8.6
0.5 to 0.1	93	92.5	72	85.5	77	81	69.5
0.1 to 0.006	5	5.5	22	12	15.1	15.5	18.1
0.006 to 0	2	1.5	2	2.5	2.2	0	0.5
Total pore volume	100	100	100	100	100	100	100
Percentage of pores (%) down to 0.1 μ corresponding to electrolyte absorption	93%	93%	76%	85.5	82.6	84.5%	81.4%
Percentage of pores (%) smaller than 0.5 μ	100%	99.5%	96%	100%	94.4	96.5%	88.1%

Incorporation of Additives

As the sintering temperature of the electrode will be higher than the decomposition temperature of HgO and PbO, it was necessary to develop a method for introducing such additives in controlled quantity and uniformly throughout the mass of the sintered zinc oxide electrode.

The principle is as follows: The electrode is dipped in an acetic acid solution where HgO or PbO has been dissolved. The amount of mercuric or lead acetate solution picked up within the pores of the electrode is enough to leave the desired percentage of HgO or PbO in the electrode when the wet electrode has been dried and submitted to approximately 150°C for 6 to 8 hours to decompose and drive off the acetic acid and acetates. Several analyses of controlled weight pellets impregnated with controlled concentration solutions gave the predicted HgO or PbO percentages. The concentration may be adjusted so that one dipping is enough to leave the desired amount of HgO or PbO in the electrode after drying and decomposing the acetate salts at high temperature. A typical procedure is given here.

The sintered pellet (or electrode) of known absorption is dipped for 4 minutes in a 10% acetate solution of desired additive and desired concentration, then dried for 1/2 hour at 100°C, then heat-treated at 150°C for 6 hours.

Using pellets of various compositions and materials, the absorption was calculated rather than measured (the two absorptions are found to be very close) to determine the desired concentration of the additive in the acetic solution. The calculated absorption is given by the formula

$$a_c\% = 100 \left(\frac{1}{d_a} - \frac{1}{d_c} \right)$$

where d_a is the apparent density easily determined by simple measurements of dimensions and weight and d_c is the composite density (or true density) as defined in Table X.

Tables XVII and XVIII give a summary of final determinations of HgO and PbO in several samples. Aiming at 2% additive, the results are reproducible within a very narrow margin. HgO was determined by chemical titration and PbO by electroplating and gravimetry.

TASK II – ELECTRICAL CHARACTERIZATION

This task deals with the fabrication, testing and evaluation of the cells using various selected electrode compositions.

TABLE XVII

MERCURIC OXIDE INCORPORATION

Pellet Composition	Calculated Absorption	% HgO in 10% Acetic Solution	HgO Content in Pellet	
			% of total weight	% of Zinc Oxide Weight
100% ZnO	20%	7.7%	2.31	2.3
90/10 OL	20%	7.0	1.70	1.9
80/20 Z	20%	6.2	1.56	2.0
80/20 OL	20%	6.2	1.52	1.9

TABLE XVIII

LEAD OXIDE INCORPORATION

Pellet Composition	Calculated Absorption	% PbO in 10% Acetic Solution	PbO Content in Pellet	
			% of total weight	% of Zinc weight
100% ZnO	20%	9.0	2.01	2.0
90/10 Z	25	6.6	1.81	2.0
90/10 Z	24	6.8	1.83	2.0
80/20Z	22	6.6	1.74	2.2
80/20 OL	19	7.3	1.66	2.1

Preliminary Cell Tests

Preliminary cell tests were started to verify a few critical milestones and establish a good basis for recommending the statistical distribution of variables to be tested within the limits imposed by the work statement.

The cell test design is certainly a critical factor in evaluating the zinc electrode. In the spirit of the work statement, two positive and one negative electrodes were used in order to make the cell zinc-limited and thus run an accelerated test to more quickly bring out the shortcomings of the zinc electrode. Rigid organic separator 3420-09 will be used as specified in the work statement. When the zinc electrode is sandwiched between two separators forming a negative wafer, the separator cracking caused by the expansion of zinc during its cycle life is very often the failure mode of silver-zinc cells using this type of construction. The reverse construction, namely the positive wafer where silver electrodes are sandwiched and zinc is left outside is not conducive to separator cracking. Thus, the zinc electrode can be fully evaluated on its own merits without extraneous factors contributing to failure. Variation of design is therefore another variable.

The wet process of HgO incorporation in the zinc electrode had to be tested in actual cells to firmly establish that it is not causing any unexpected effect.

Various ratios of inorganic to ZnO had to be scanned quickly to narrow down the choice of the variables. This ratio varied from 5% to 20%.

The design characteristics are as follows:

Positive:	Dimensions:	1.6" x 1.6" x 0.22"
	Silver Weight:	4.5 g
Negative:	Dimensions:	1.6" x 1.6" x 0.070" (including KT)
	Mix Material:	6 g
	HgO:	2%

The cells were cycled at 100% depth as follows:

Charge:	100 mA to 2.10 V
Discharge:	600 mA to 1.0 V

Two groups of cells were fabricated (each variation includes three cells), covering a total of 24 cells.

Series ZN-25: Encapsulated Negatives

This series includes five groups of three cells each (all of the negative encapsulated type design).

Group A	Control: Regular zinc oxide electrode (not sintered)
Group B	Sintered electrode: 100% ZnO
Group C	Sintered electrode: 95% ZnO, 5% zirconia
Group D	Sintered electrode: 90% ZnO, 10% zirconia
Group E	Sintered electrode: 80% ZnO, 20% zirconia

All electrodes had the same amount of mix material regardless of composition.

The cells were submitted to eight deep discharge cycles at 0.6 A to 1.0 V. The 80/20 Z material electrode output is lower than 80% of that of the control on every cycle. The outputs of other electrodes are very close to one another, even after eight cycles. The same holds true for the average plateau voltages. They were then placed on the automatic cycling regime No. 2, as described in the work statement, viz. discharge at 1.2 A for 1/2 hour; charge at 0.66 A for 1 hour.

After a certain number of cycles, the cells were not able to sustain such a high rate regime and were switched to a lower rate regime (discharge at 0.8 A for 1/2 hour; charge at 0.5 A for 1 hour).

Tables XIX and XX give all cycles at various rates and other pertinent information.

Series ZN-31: Encapsulated Positives

This series includes three groups of three cells each (all of the positive encapsulated design type).

Group A	Control: Regular zinc oxide electrode (not sintered)
Group B	Sintered electrode: 100% ZnO
Group C	Sintered electrode: 90% ZnO, 10% zirconia

The cells were submitted to seven deep discharge cycles at 0.6 A to 1.0 V then placed on the automatic cycling regime No. 2 described above.

TABLE XIX

TEST DATA OF ZN-25 CELLS WITH NEGATIVE WAFER

Discharge: 600 mA to 1.0 V
Charge: 100 mA to 2.10 V

Variation	Group	Cycle							
		1	2	3	4	5	6	7	8
Average Capacity (Ah)									
Control ZnO	A	2.8 Ah	2.3	2.5	2.3	2.3	2.2	1.8	2.1
Sintered 100% ZnO	B	2.5	2.3	2.2	2.1	2.2	2.2	2.0	2.0
95/5 Z	C	2.5	2.2	2.1	2.0	2.2	2.0	2.0	2.0
90/10 Z	D	2.4	2.1	2.0	1.9	2.1	1.9	1.9	1.9
80/20 Z	E	2.0	1.7	1.5	1.5	1.5	1.4	1.4	1.3
Average Plateau Voltage (Volts)									
Control ZnO	A	1.42 V	1.41	1.41	1.41	1.42	1.43	1.42	1.40
Sintered 100% ZnO	B	1.42	1.40	1.38	1.39	1.39	1.40	1.42	1.39
95/5 Z	C	1.41	1.40	1.39	1.39	1.38	1.41	1.39	1.40
90/10 Z	D	1.38	1.38	1.39	1.39	1.38	1.39	1.40	1.40
80/20 Z	E	1.36	1.33	1.35	1.36	1.36	1.36	1.38	1.36

TABLE XX

CYCLING CAPABILITY OF CELLS WITH NEGATIVE WAFER

(ZN-25 Series)

Group and Variation	Cell No.	Cycles at Indicated Regime				Total Cycles	Wet Life (days)	Last Capacity Check Ah (Cycle No.)
		Charge	0.1 A to 2.10 V	0.66 A for 1 hr	0.5 A for 1 hr			
		Discharge	0.6 A to 1.0 V	1.20 A for 1/2 hr	0.8 A for 1/2 hr			
A (Control ZnO)	1		8	209*	100+	317+	67	2.0 (317)
	2		8	264*	51+	328+	64	1.3 (210)
	3		8	208*	85+	301+	67	1.7 (301)
B (Sintered) ZnO)	4		8	190	78	276	73	0.4 (198)
	5		8	190	113	311	78	0.5 (197)
	6		8	190	34	232	80	0.3 (197)
C (95/5 Z)	7		8	190	1	199	68	0.4 (199)
	8		8	190	2	200	68	0.6 (200)
	9		8	189	0	197	48	0.7 (197)
D (90/10 Z)	10		8	82	125	215	71	0.3 (215)
	11		8	82	111	201	71	0.3 (201)
	12		8	77	118	203	70	0.4 (203)
E (80/20 Z)	13		8	51	50+	109+	66	1.0 (109)
	14		8	66	74+	148+	68	1.0 (148)
	15		8	61	79+	148+	68	0.9 (148)

* Switched to other regime before failure.

+ Cells still capable of limited cycling.

Tables XXI and XXII give a summary of their cycling data.

As suspected, the high rate charge of this regime (22 mA/cm^2) imposes a severe penalty on the cells; cycle life falls then in the range of 200 cycles. This was demonstrated on several 5 Ah Ag-Zn cells of the NASA contract NAS 3-10924* where a similar regime with prorated charge and discharge currents, called regime E, gave the same type of results (data obtained were erratic and ranged from 55 to 400 cycles, with a representative average of 250 cycles).

It was recommended that this regime be revised as being in conflict with other cell design features. The separator used or to be used is known to be satisfactory only at relatively low rates; the plate area called out is such that the current density is ipso facto very high on discharge and on charge; this in turn causes an inordinate amount of gassing because of the necessary overcharge to keep the cell cycling.

All these factors obviously give erratic cycling results and may blur the value of a new zinc electrode composition.

Selection of Combinations of Variables

The variables and variable levels to be considered would lead to a high number of combinations of electrode construction features. A discriminative selection was made jointly with the NASA Program Manager in order to limit this number to 20 as required by the work statement with two control groups, A and B (defined later). Under the direction of the NASA Program Manager, the cells were fabricated in different groups at various times of the program, as data were generated.

Prior to fabrication, it was decided not to consider the inorganic binder OL because it was recognized that the presence of iron in its composition would cause undesirable gassing in the zinc electrode. Only one inorganic binder (zirconia) was used.

The variables and levels selected were narrowed down to the following:

---

*A. Himy, Development and Testing of a Five Ah Silver-Zinc Cell, Final Report NASA CR-72551, Astropower Laboratory, McDonnell Douglas Astronautics Company, Western Division, July 1969.

TABLE XXI

TEST DATA OF ZN-31 CELLS WITH POSITIVE WAFER

Discharge: 0.6 A to 1.0 V

Charge: 100 mA to 2.10 V

Average Capacity (Ah)							
Variation	Group	Cycle					
		1	2	3	4	5	6
Control ZnO	A	2.2	2.7	2.4	2.1	2.1	2.1
Sintered 100% ZnO	B	2.1	2.8	2.2	2.1	2.3	2.1
90/10 Z	C	2.2	2.6	2.2	2.1	2.3	2.2
Average Plateau Voltage (volts)							
Control ZnO	A	1.36	1.40	1.41	1.42	1.40	1.42
Sintered 100% ZnO	B	1.37	1.38	1.40	1.38	1.39	1.40
90/10 Z	C	1.39	1.39	1.40	1.40	1.40	1.40

TABLE XXII

CYCLING CAPABILITY OF CELLS WITH POSITIVE WAFERS

(ZN-31 Series)

Group and Variation	Cell No.	Cycles at Indicated Regime				Total Cycles	Wet Life (days)	Last Capacity Check Ah (Cycle No.)
		Charge	0.1 A to 2.10 V	0.66 A for 1 hr	0.5 A for 1 hr			
		Discharge	0.6 A to 1.0 V	1.2 A for 1/2 hr	0.8 A for 1/2 hr			
A (Control ZnO)	1		7	229	–	236	54	0.7 (236)
	2		7	230	133	370	80	0.7 (237)
	3		7	230	16	253	69	0.7 (253)
B (Sintered ZnO)	4		7	273	126	406	71	0.5 (406)
	5		7	274*	188	469	73	0.9 (216)
	6		7	274*	96	377	67	0.8 (377)
C (90/10 Z)	7		7	206	–	213	64	–
	8		7	227	–	284	65	1.0 (234)
	9		7	206	–	213	64	–

* Switched to other regime before failure.

Inorganic Binder:	Zirconia (Z)
Ratio:	95/5, 90/10, 80/20
Process:	Normal (N), Presinter (PS)
Additives (Hg, Pb):	(2%, 0%), (2%, 1%), (2%, 2%)
Grid in zinc electrode:	Exmet 5 Ag-14-1/0 (flat structure) Distex 5 Ag-38-1/0 (honeycomb)
Design:	Encapsulated negative or negative wafer (-) w Encapsulated positive or positive wafer (+) W
Separator:	3420-09, 3420-25

The following were maintained constant:

The sintering temperature (850°C)

The electrolyte concentration (30% KOH)

The negative and positive interseparators (10 mil-KT)

The electrode thickness, weight and porosity.

All combinations and control groups are listed in Table XXIII, although not in chronological order. The successive tests were as follows:

(a) Combinations 1 to 4 were intended to screen out minor variables. Using one binder material Z, one ratio (90/10), one process (normal), a standard amount of amalgamation (2%), and separator 3420-09, the variations were carried out on the grid (Exmet 5 Ag-14-1/0, which presents a flat structure and Distex 5 Ag-38-1/0, which presents a honeycomb structure) and on the electrode pack assembly design (encapsulated negative contrasted to encapsulated positive). Control group A used standard zinc oxide electrodes, made with unsintered zinc oxide mix containing 2% HgO and using the Distex grid and the encapsulated negative design.

(b) Combinations 5 through 12 had one important change besides electrode compositions: NASA Technical Direction No. 2, dated 1/22/69, and No. 3, dated 1/10/69, ordered the use of separator 3420-25. Control group B is essentially the same as control group A except the change in separator.

(c) Combinations 13 through 20 used the former separator, 3420-09, as redirected by NASA Technical Direction No. 5, dated 4/23/69.

TABLE XXIII

COMBINATIONS OF ELECTRODE VARIABLES

Comb. No.	Separator	Grid	Design (wafer)	Ratio (ZnO/Binder)	Process	Additive (PbO %)
A	3420-09	Distex	(-) w	100/0	Not sintered	0
1	"	Exmet	(+) w	90/10	N	0
2	"	Exmet	(-) w	"	N	0
3	"	Distex	(+) w	"	N	0
4	"	Distex	(-) w	"	N	0
13	"	Exmet	"	"	N	1
14	"	"	"	"	N	2
15	"	"	"	"	PS	1
16	"	"	"	"	PS	2
17	"	"	"	80/20	N	1
18	"	"	"	"	N	2
19	"	"	"	"	PS	1
20	"	"	"	"	PS	2
B	3420-25	Distex	(-) w	100/0	Not sintered	0
5	"	Exmet	"	90/10	N	0
6	"	"	"	"	N	1
7	"	"	"	"	PS	0
8	"	"	"	"	PS	1
9	"	"	"	95/5	N	0
10	"	"	"	"	N	1
11	"	"	"	"	PS	0
12	"	"	"	"	PS	1

Constant: Binder: Zirconia
Sintering Temp: 850°C
Amalgamation: 2% HgO

Each combination or group consisted of nine cells to be tested in subgroups of three cells on three different regimes.

The breakdown of the number of cells (limited by the work statement to a maximum of 250) is as follows:

Preliminary cell tests:	24
20 combinations and 2 control groups:	198
Repeat of 2 combinations:	24
Zinc efficiency tests:	4
	250

Testing

All cells were first tested identically. After a formation cycle, they were submitted to four deep discharge cycles, each at a different rate.

After these five manual cycles, they were divided in groups of three cells each, which were submitted to different automatic cycling regimes.

The manual cycling consisted of a formation at 100 mA charge to 2.10 V cut-off (maximum time limited to 24 hours) and 600 mA discharge to 1.0 V, followed by four cycles each at a different rate to 0.9 V cut-off:

30 mA

600 mA

1.5 A

3.0 A

The automatic cycling covers three regimes defined as follows:

Regime	1	2*	3
Temperature	100°C	25°C	25°C
Period	1 hour	1.5 hours	24 hours
Discharge	0.60 A/0.5 hr	0.9 A/0.5 hr	1.2 A/1.2 hr
Charge	0.66 A/0.5 hr	0.50 A/1 hr	70 mA/22.8 hr

*The original regime No. 2 (discharge at 1.2 A for 1/2 hour, charge at 0.66 A for 1 hour) was modified by NASA Technical Direction No. 3. dated 1/10/60.

The cells were cycled continuously and stopped about every 100 cycles for a capacity check on Regimes 1 and 2, corresponding to 4 days cycling on Regime 1 and 6 days on Regime 2. The capacity check of cells on Regime 3 was done only every 30 cycles, corresponding to 30 days cycling time. The tables presenting cycling data refer to this operation as check points.

When a technical failure occurred (discharge voltage dropping below 1.0 V before the end of the discharge period), the cell was recharged and its capacity checked. If it was found to be over the cycling capacity requirement, the cell was put back on cycling. The tables presenting cycling data refer to this operation as cycling failures. In several instances, however, in the later part of the program, it was found desirable to avoid repeated and frequent 100% depth-of-discharge cycles which may cut down on the performance of the cell cycling on a particular regime. Therefore, in agreement with the NASA program manager, it was decided to give the cell two consecutive charge periods (skipping a discharge) if it reaches a cycling failure; the cell was then left cycling if it resumed its normal cycling performance.

When the cell failed completely, the failure was classified as technical failure (TF) if the cell could not meet the cycling capacity requirement on a capacity check, or catastrophic failure (CF) if the cell could not cycle or accept charge.

Control Group A and Combinations 1 through 4

Manual Cycling

The data of the five manual deep cycles given to each combination (group of nine cells) are presented in Tables XXIV through XXVIII.

Capacity and plateau voltage variation with discharge rates are shown graphically in Figures 20 through 23. Figure 24 shows a typical set of discharge curves at various rates.

The cells of combinations 1 through 4, destined to be placed on automatic regimes 1 and 2, were discontinued after approximately 200 cycles for regime No. 1 (because they were by error cycled at room temperature instead of 100°C) and approximately 80 cycles for regime No. 2 (because the discharge rate, originally 1.2 A, was modified to 0.9 A by NASA Technical Direction No. 3). Consequently, the 24 cells involved were discontinued. The automatic cycling data of these cells are presented in Tables XXIX to XXXII.

New cells were fabricated for the correct tests. Tables XXXIII to XXXVI give the manual cycling data of the new cells noted A affixed to

TABLE XXIV

PRECYCLING TEST DATA

Control Group A (3420-09)

Cell Number	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage
A-11	2.1 Ah	1.41 V	2.4 Ah	1.52 V	1.8 Ah	1.42 V	1.8 Ah	1.30 V	1.5 Ah	1.17 V
A-12	2.1 Ah	1.41 V	2.6 Ah	1.52 V	1.8 Ah	1.42 V	2.0 Ah	1.31 V	1.8 Ah	1.18 V
A-13	2.0 Ah	1.41 V	2.5 Ah	1.52 V	1.9 Ah	1.42 V	1.8 Ah	1.29 V	1.7 Ah	1.16 V
A-21	2.1 Ah	1.41 V	2.6 Ah	1.52 V	2.0 Ah	1.43 V	2.0 Ah	1.31 V	1.7 Ah	1.19 V
A-22	1.9 Ah	1.41 V	2.4 Ah	1.52 V	1.9 Ah	1.43 V	2.0 Ah	1.32 V	1.7 Ah	1.19 V
A-23	2.0 Ah	1.42 V	2.4 Ah	1.52 V	1.9 Ah	1.41 V	1.9 Ah	1.31 V	1.7 Ah	1.17 V
A-31	2.0 Ah	1.42 V	2.5 Ah	1.52 V	2.0 Ah	1.43 V	2.0 Ah	1.32 V	1.8 Ah	1.20 V
A-32	2.0 Ah	1.42 V	2.5 Ah	1.52 V	1.9 Ah	1.42 V	2.1 Ah	1.31 V	1.7 Ah	1.18 V
A-33	2.0 Ah	1.42 V	2.6 Ah	1.52 V	1.9 Ah	1.43 V	2.1 Ah	1.32 V	1.8 Ah	1.19 V
Average	2.0 Ah	1.42 V	2.5 Ah	1.52 V	1.9 Ah	1.42 V	2.0 Ah	1.31 V	1.7 Ah	1.18 V

TABLE XXV

PRECYCLING TEST DATA

Combination No. 1

Cell No.	Formation (0.6 Ah)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)
111	2.3	1.42	2.3	1.50	2.3	1.40	2.0	1.30	1.9	1.18
112	2.3	1.41	2.3	1.50	2.2	1.36	1.7	1.30	1.8	1.17
113	2.3	1.42	2.3	1.50	1.9	1.34	1.8	1.30	1.8	1.19
121	2.3	1.40	2.3	1.50	2.3	1.39	1.8	1.28	1.9	1.18
122	2.3	1.41	2.3	1.50	2.3	1.40	2.0	1.31	1.9	1.17
123	2.3	1.41	2.3	1.50	2.1	1.36	1.7	1.28	1.8	1.16
131	2.3	1.42	2.3	1.50	2.3	1.40	2.0	1.32	1.8	1.19
132	2.3	1.42	2.2	1.50	2.1	1.39	2.0	1.30	1.9	1.19
133	2.3	1.41	2.2	1.50	2.3	1.38	1.8	1.30	1.9	1.20
Avg	2.3	1.41	2.3	1.50	2.2	1.38	1.8	1.30	1.8	1.18

TABLE XXVI

PRECYCLING TEST DATA

Combination No. 2

Cell No.	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)
211	2.3	1.37	2.4	1.48	2.2	1.40	1.8	1.33	1.5	1.18
212	2.3	1.36	2.2	1.49	2.3	1.40	1.7	1.32	1.5	1.14
213	2.3	1.39	2.3	1.46	2.3	1.42	2.1	1.32	1.9	1.20
221	2.3	1.37	2.4	1.48	2.1	1.40	1.7	1.30	1.5	1.19
222	2.3	1.36	2.4	1.49	2.3	1.39	1.7	1.30	1.2	1.16
223	2.3	1.35	2.4	1.49	1.9	1.39	1.7	1.29	1.2	1.15
231	2.3	1.37	2.3	1.47	2.3	1.41	2.0	1.30	1.8	1.19
232	2.3	1.33	2.4	1.50	2.2	1.39	1.7	1.28	1.2	1.10
233	2.3	1.32	2.4	1.50	2.0	1.40	1.8	1.30	1.5	1.16
Avg	2.3	1.36	2.4	1.49	2.2	1.40	1.8	1.29	1.5	1.16

TABLE XXVII

PRECYCLING TEST DATA

Combination No. 3

Cell No.	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)
311	2.3	1.39	2.4	1.50	2.1	1.40	2.0	1.31	2.0	1.20
312	2.3	1.40	2.3	1.50	2.3	1.42	2.3	1.32	2.3	1.24
313	2.3	1.40	2.3	1.50	2.3	1.41	2.2	1.32	2.3	1.24
321	2.3	1.40	2.3	1.50	2.1	1.40	2.1	1.31	2.0	1.20
322	2.3	1.41	2.2	1.50	2.2	1.30	2.2	1.31	2.3	1.20
323	2.3	1.41	2.2	1.50	2.3	1.40	2.1	1.30	2.2	1.22
331	2.3	1.40	2.3	1.50	2.1	1.39	1.9	1.30	2.0	1.16
332	2.3	1.40	2.4	1.50	2.1	1.40	2.0	1.30	2.0	1.20
333	2.3	1.40	2.4	1.50	2.1	1.40	1.9	1.30	2.0	1.16
Avg	2.3	1.40	2.3	1.50	2.2	1.40	2.1	1.31	2.1	1.20

TABLE XXVIII

PRECYCLING TEST DATA

Combination No. 4

Cell No.	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (0.5 A)		Cycle 4 (3 A)	
	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)
411	2.3	1.39	2.4	1.50	1.8	1.36	1.7	1.28	1.5	1.12
412	2.3	1.36	2.4	1.50	1.9	1.38	1.6	1.30	1.5	1.16
413	2.3	1.38	2.4	1.50	1.9	1.36	1.7	1.30	1.5	1.16
421	2.3	1.38	2.4	1.50	2.1	1.38	1.8	1.30	1.8	1.20
422	2.3	1.36	2.4	1.50	1.8	1.36	1.8	1.29	1.2	1.10
423	2.3	1.36	2.3	1.50	1.9	1.38	1.7	1.30	1.5	1.16
431	2.3	1.40	2.4	1.50	2.0	1.39	1.7	1.32	1.5	1.18
432	2.3	1.38	2.4	1.50	1.9	1.36	1.6	1.31	1.5	1.18
433	2.3	1.36	2.4	1.50	1.9	1.38	1.8	1.31	1.8	1.18
Avg	2.3	1.38	2.4	1.50	1.9	1.37	1.7	1.30	1.5	1.16

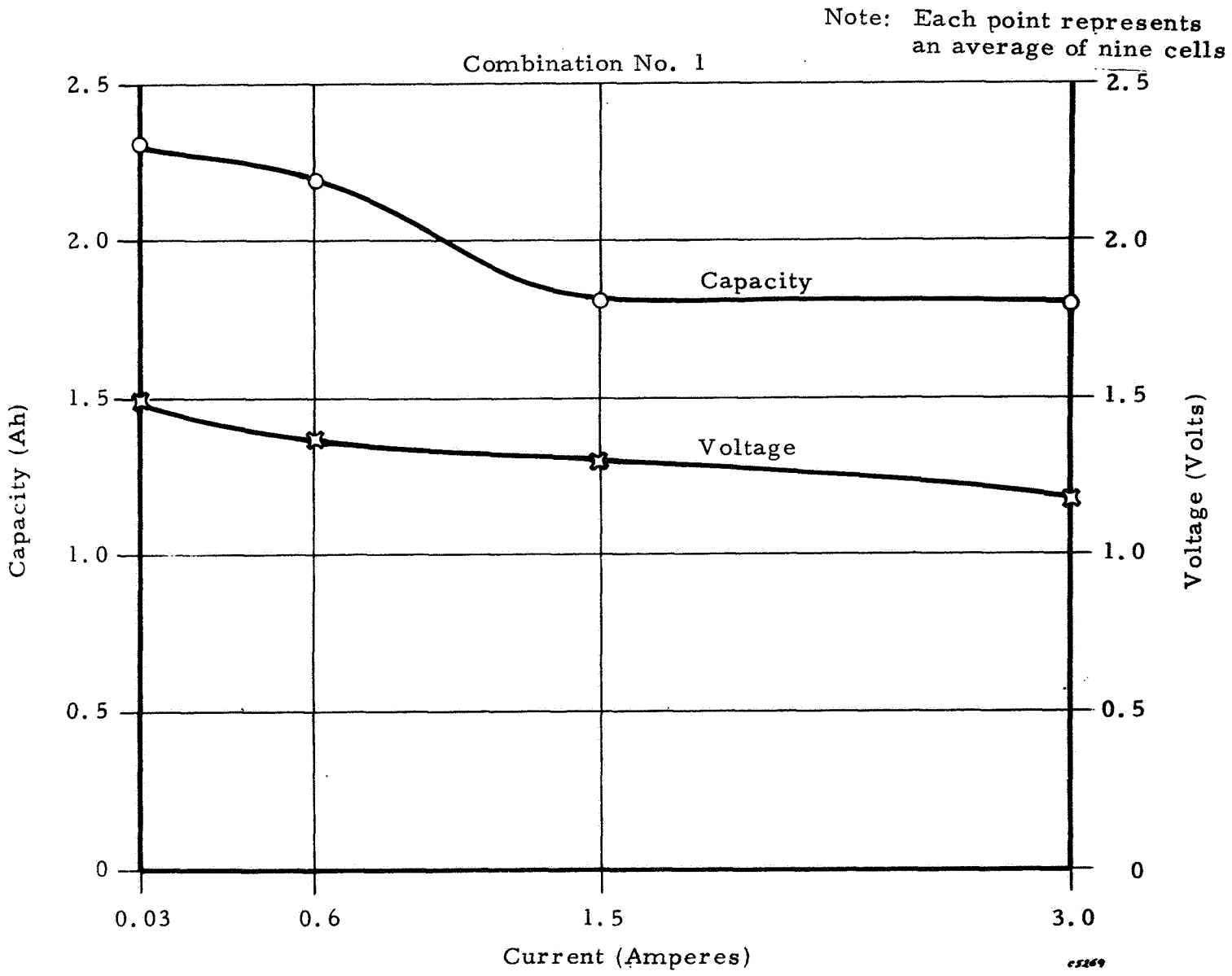


Figure 20. Capacity and Plateau Voltage During First Four Cycles

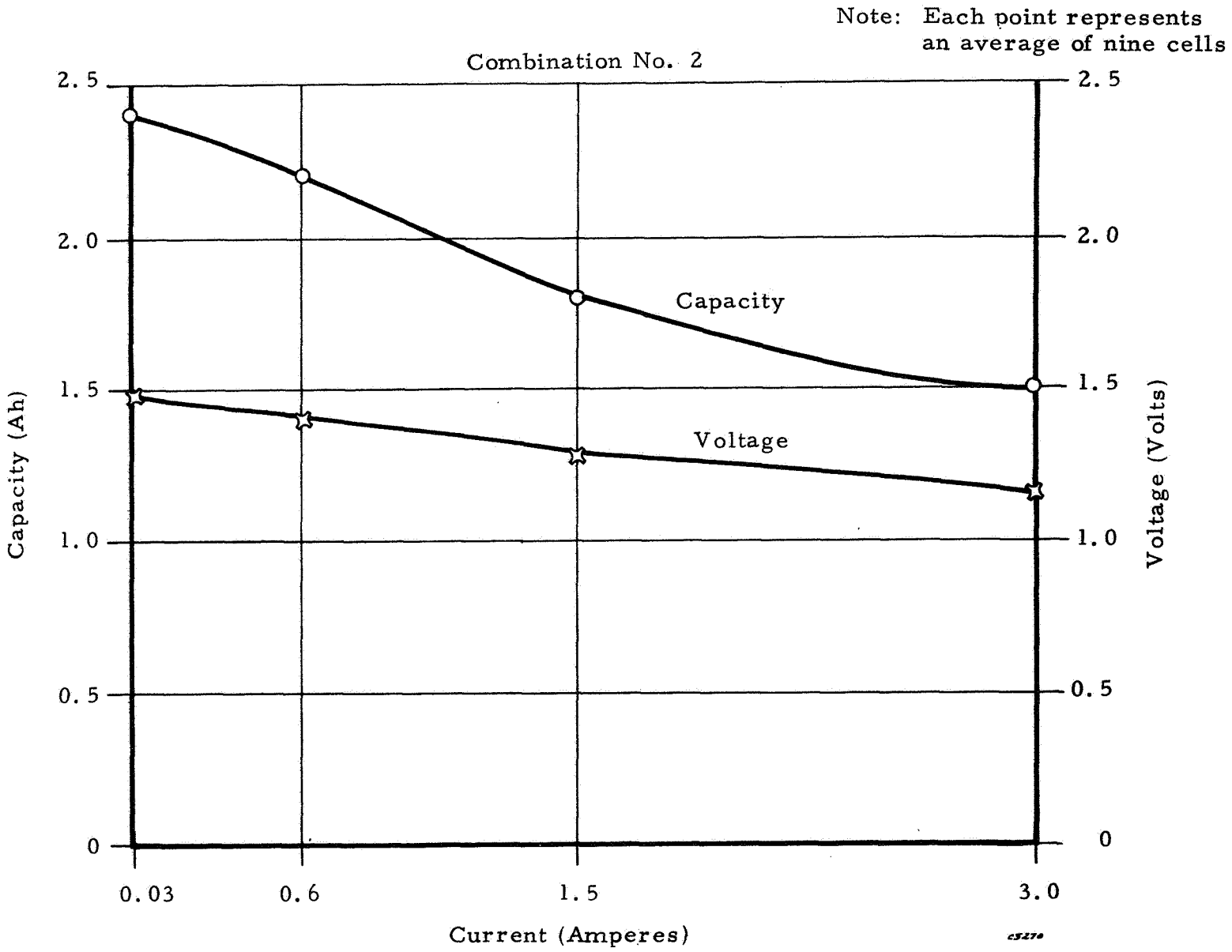


Figure 21. Capacity and Plateau Voltage During First Four Cycles

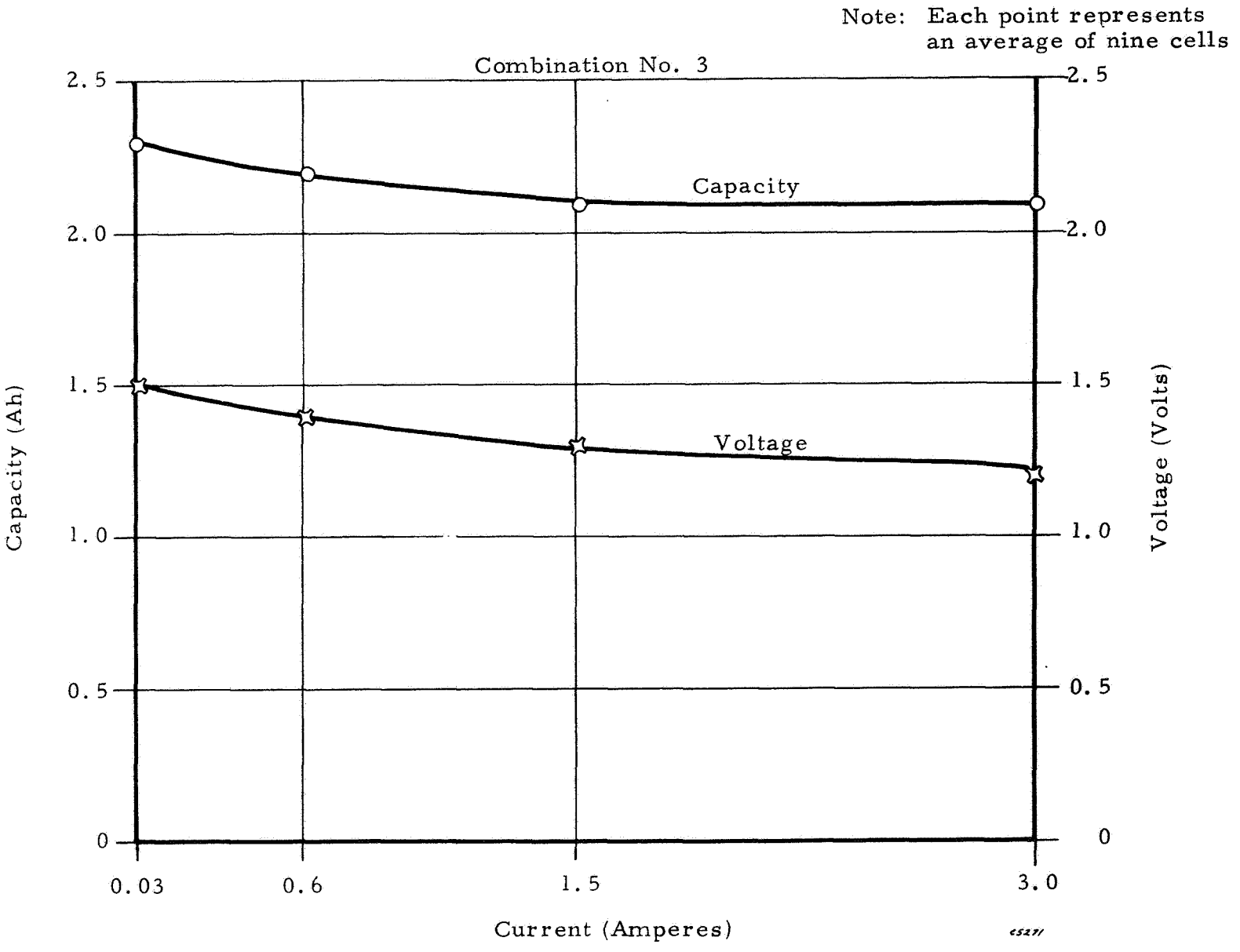


Figure 22. Capacity and Plateau Voltage During First Four Cycles

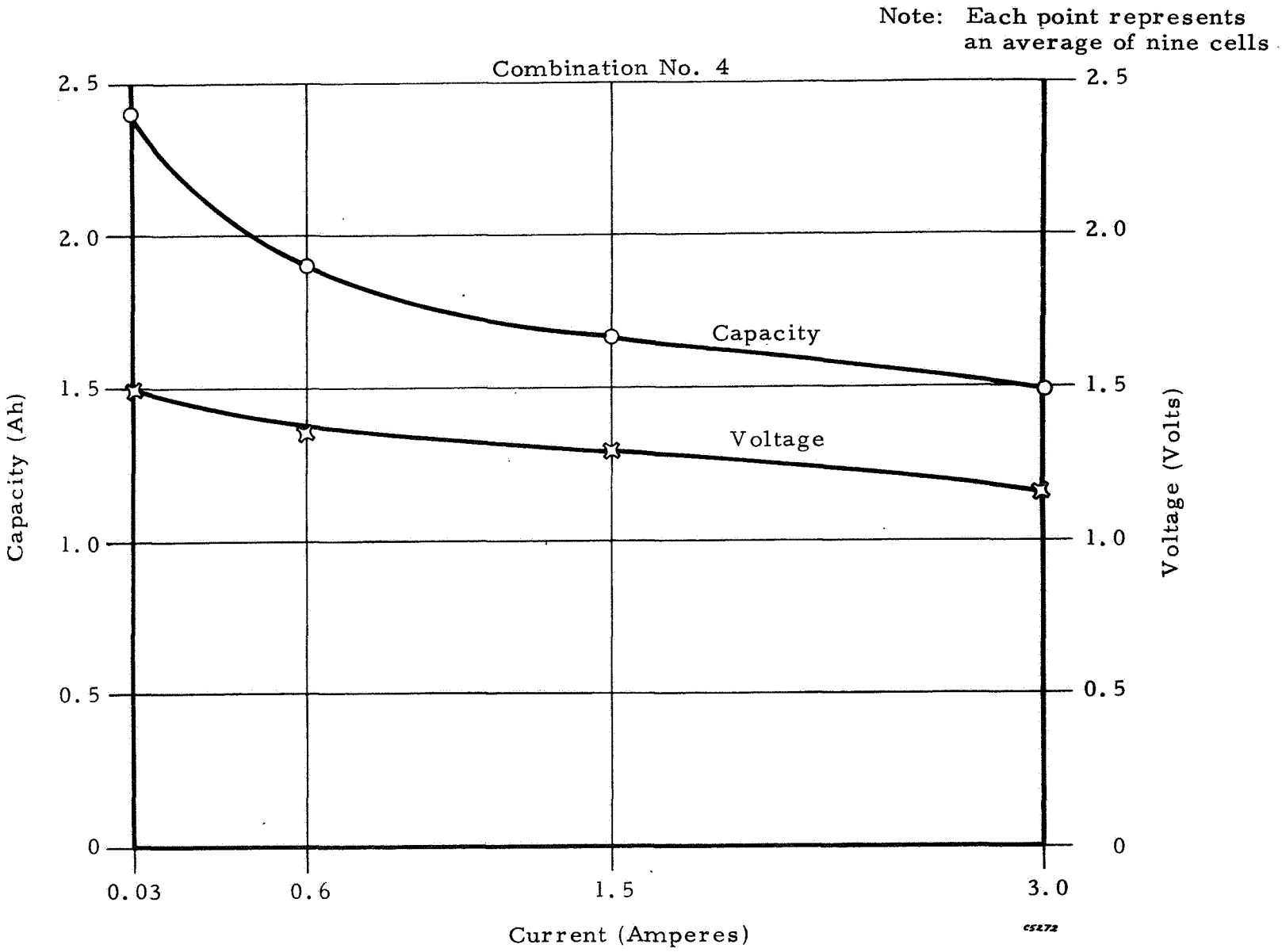


Figure 23. Capacity and Plateau Voltage During First Four Cycles

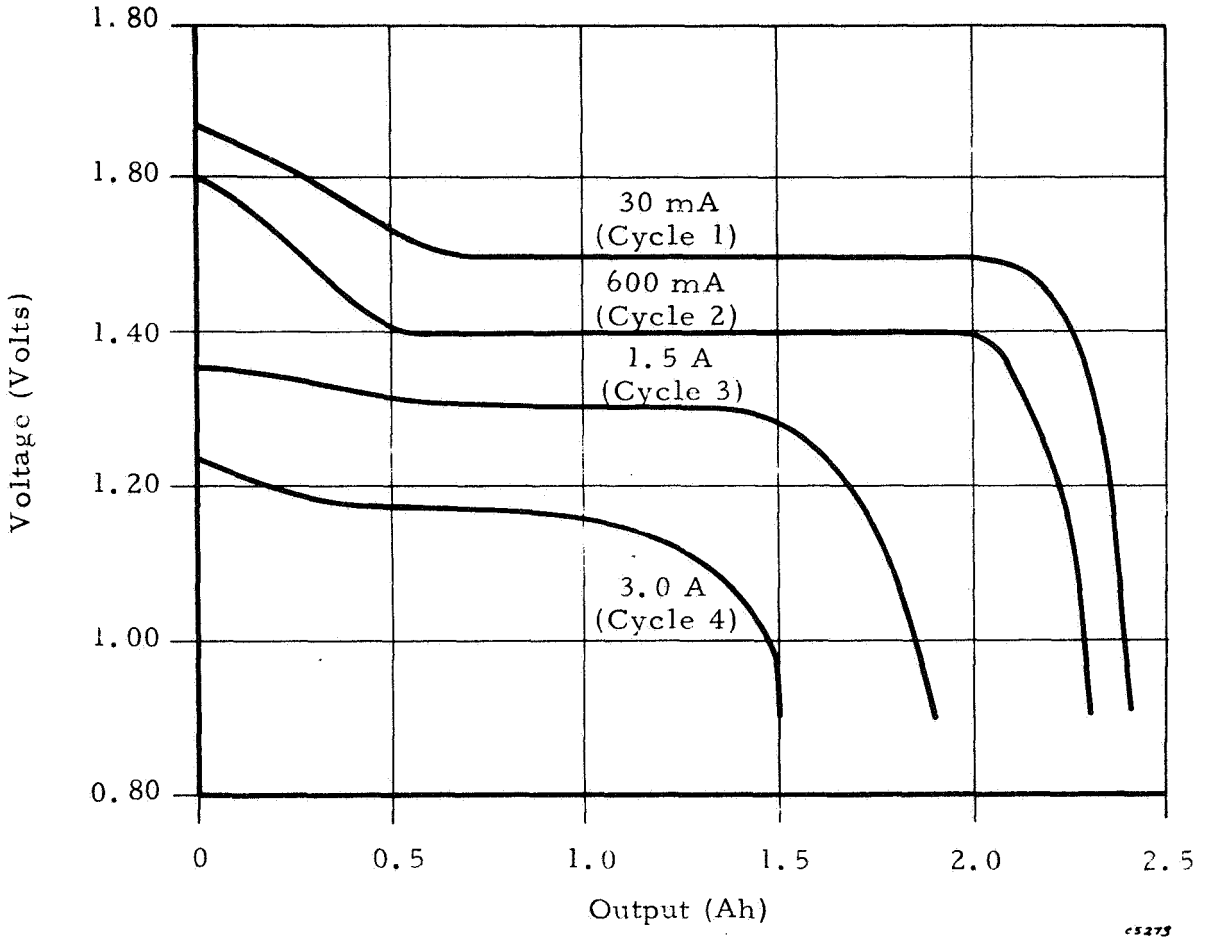


Figure 24. Typical Discharge Curves of Test Cells During the First Four Cycles

TABLE XXIX

TEST DATA ON COMBINATION NO. 1 (ORIGINAL)

Cell No.	Regime 1 (25°C)			Regime 2 (1.2 A)		
	111	112	113	121	122	123
Capacity Checks						
1. N(Q)	104 (1.6)	104 (1.4)	104 (1.4)	88 (1.3)	84 (1.4)	53 (1.4)
2. N(Q)	171 (1.4)	197 (1.3)	181 (1.2)			
3. N(Q)						
4. N(Q)						
5. N(Q)						
Status Cycle	171	197	181	88	84	53
Failure Mode	(+)	(+)	(+)	(+)	(+)	(+)

Regime 1:

Run at 25°C by error instead of 100°C; cells were discontinued and replaced with new ones.

Regime 2:

Run at the original 1.2 A discharge rate modified by NASA to 0.9 A; cells were discontinued and replaced with new ones.

TF = Technical Failure – Cell cannot deliver the cycling requirement output on a capacity check.

CF = Catastrophic Failure – Cell cannot accept charge or cycle.

N(Q) = Cycle Number (Capacity)

(+) = Cell still cycling when stopped at indicated cycle.

TABLE XXX

TEST DATA ON COMBINATION NO. 2 (ORIGINAL)

Cell No.	Regime 1 (25°C)			Regime 2 (1.2 A)		
	211	212	213	221	222	223
Capacity Checks						
1. N(Q)	104 (1.6)	104 (1.4)	104 (1.9)	59 (1.4)	89 (1.3)	84 (1.4)
2. N(Q)	125 (1.4)	179 (1.4)	200 (1.4)			
3. N(Q)						
4. N(Q)						
5. N(Q)						
Status Cycle	125	179	200	59	89	84
Failure Mode	(+)	(+)	(+)	(+)	(+)	(+)

Regime 1:

Run at 25°C by error instead of 100°C; cells were discontinued and replaced with new ones.

Regime 2:

Run at the original 1.2 A discharge rate modified by NASA to 0.9 A; cells were discontinued and replaced with new ones.

TF = Technical Failure – Cell cannot deliver the cycling requirement output on a capacity check.

CF = Catastrophic Failure – Cell cannot accept charge or cycle.

N(Q) = Cycle Number (Capacity)

(+) = Cell still cycling when stopped at indicated cycle.

TABLE XXXI

TEST DATA ON COMBINATION NO. 3 (ORIGINAL)

Cell No.	Regime 1 (25°C)			Regime 2 (1.2 A)		
	311	312	313	321	322	323
Capacity Checks						
1. N(Q)	100 (1.4)	51 (2.0)	100 (1.7)	118(1.2)	118(1.4)	53 (1.4)
2. N(Q)		120 (1.5)				
3. N(Q)						
4. N(Q)						
5. N(Q)						
Status Cycle	100	120	100	118	118	53
Failure Mode	(+)	(+)	(+)	(+)	(+)	(+)

TF = Technical Failure – Cell cannot deliver the cycling requirement output on a capacity check.

CF = Catastrophic Failure – Cell cannot accept charge or cycle.

N(Q) = Cycle Number (Capacity)

(+) = Cell still cycling when stopped at indicated cycle.

Regime 1:

Run at 25°C by error instead of 100°C; cells were discontinued and replaced with new ones.

Regime 2:

Run at the original 1.2 A discharge rate modified by NASA to 0.9 A; cells were discontinued and replaced with new ones.

TABLE XXXII

TEST DATA ON COMBINATION NO. 4 (ORIGINAL)

Cell No.	Regime 1 (25°C)			Regime 2 (1.2 A)		
	411	412	413	421	422	423
Capacity Checks						
1. N(Q)	104 (1.5)	104 (1.4)	104 (1.5)	89 (1.1)	54 (1.7)	86 (1.3)
2. N(Q)		200 (1.2)	178 (1.2)			
3. N(Q)						
4. N(Q)						
5. N(Q)						
Status Cycle	104	200	178	89	54	86
Failure Mode	(+)	(+)	(+)	(+)	(+)	(+)

Regime 1:

Run at 25°C by error instead of 100°C; cells were discontinued and replaced with new ones.

Regime 2:

Run at the original 1.2 A discharge rate modified by NASA to 0.9 A; cells were discontinued and replaced with new ones.

TF = Technical Failure – Cell cannot deliver the cycling requirement output on a capacity check.

CF = Catastrophic Failure – Cell cannot accept charge or cycle.

N(Q) = Cycle Number (Capacity)

(+) = Cell still cycling when stopped at indicated cycle.

TABLE XXXIII

PRECYCLING TEST DATA

Combination No. 1 (Repeat)

Cell Number	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage
111 A	2.2 Ah	1.39 V	2.3 Ah	1.50 V	2.0 Ah	1.38 V	1.5 Ah	1.26 V	1.1 Ah	1.20 V
112 A	2.1 Ah	1.39 V	2.3 Ah	1.50 V	2.0 Ah	1.37 V	1.4 Ah	1.21 V	1.1 Ah	1.17 V
113 A	2.1 Ah	1.39 V	2.3 Ah	1.51 V	1.8 Ah	1.37 V	1.4 Ah	1.20 V	1.0 Ah	1.13 V
121 A	2.2 Ah	1.39 V	2.3 Ah	1.50 V	2.1 Ah	1.40 V	1.7 Ah	1.27 V	1.3 Ah	1.19 V
122 A	2.2 Ah	1.39 V	2.3 Ah	1.51 V	1.9 Ah	1.37 V	1.3 Ah	1.20 V	1.0 Ah	1.13 V
123 A	2.1 Ah	1.38 V	2.3 Ah	1.51 V	2.0 Ah	1.36 V	1.4 Ah	1.18 V	1.0 Ah	1.10 V
Average	2.15 Ah	1.39 V	2.3 Ah	1.50 V	2.0 Ah	1.38 V	1.5 Ah	1.22 V	1.1 Ah	1.15 V

TABLE XXXIV

PRECYCLING TEST DATA

Combination No. 2 (Repeat)

Cell Number	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage
211 A	2.2 Ah	1.40 V	2.5 Ah	1.52 V	2.1 Ah	1.37 V	2.0 Ah	1.24 V	1.0 Ah	1.17 V
212 A	2.1 Ah	1.39 V	2.5 Ah	1.52 V	1.9 Ah	1.36 V	1.9 Ah	1.27 V	1.0 Ah	1.18 V
213 A	2.2 Ah	1.38 V	2.5 Ah	1.52 V	2.0 Ah	1.38 V	1.4 Ah	1.20 V	1.0 Ah	1.15 V
221 A	2.2 Ah	1.38 V	2.5 Ah	1.51 V	2.1 Ah	1.35 V	1.6 Ah	1.23 V	0.9 Ah	1.08 V
222 A	2.2 Ah	1.38 V	2.4 Ah	1.52 V	2.0 Ah	1.36 V	1.4 Ah	1.18 V	0.9 Ah	1.08 V
223 A	2.0 Ah	1.40 V	2.5 Ah	1.52 V	1.8 Ah	1.42 V	1.9 Ah	1.25 V	1.2 Ah	1.15 V
Average	2.2 Ah	1.39 V	2.5 Ah	1.52 V	2.0 Ah	1.37 V	1.7 Ah	1.23 V	1.0 Ah	1.14 V

TABLE XXXV

PRECYCLING TEST DATA

Combination No. 3 (Repeat)

Cell Number	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage
311 A	2.3 Ah	1.39 V	2.3 Ah	1.52 V	2.0 Ah	1.38 V	1.5 Ah	1.24 V	1.0 Ah	1.22 V
312 A	2.1 Ah	1.39 V	2.3 Ah	1.52 V	2.0 Ah	1.36 V	1.3 Ah	1.19 V	0.9 Ah	1.12 V
313 A	2.1 Ah	1.39 V	2.3 Ah	1.51 V	2.1 Ah	1.38 V	1.6 Ah	1.19 V	1.0 Ah	1.16 V
321 A	2.1 Ah	1.38 V	2.3 Ah	1.51 V	1.9 Ah	1.35 V	1.2 Ah	1.18 V	1.0 Ah	1.10 V
322 A	2.2 Ah	1.39 V	2.3 Ah	1.51 V	2.0 Ah	1.38 V	1.4 Ah	1.19 V	1.0 Ah	1.14 V
323 A	2.2 Ah	1.39 V	2.3 Ah	1.51 V	2.1 Ah	1.38 V	1.5 Ah	1.21 V	1.0 Ah	1.18 V
Average	2.2 Ah	1.39 V	2.3 Ah	1.51 V	2.0 Ah	1.37 V	1.4 Ah	1.20 V	1.0 Ah	1.15 V

TABLE XXXVI

PRECYCLING TEST DATA

Combination No. 4 (Repeat)

Cell Number	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage
411 A	2.2 Ah	1.39 V	2.4 Ah	1.51 V	2.2 Ah	1.40 V	1.8 Ah	1.26 V	1.1 Ah	1.13 V
412 A	2.2 Ah	1.36 V	2.4 Ah	1.51 V	2.0 Ah	1.37 V	1.3 Ah	1.20 V	0.9 Ah	1.13 V
413 A	2.2 Ah	1.37 V	2.4 Ah	1.51 V	2.1 Ah	1.39 V	1.5 Ah	1.24 V	0.9 Ah	1.16 V
421 A	2.3 Ah	1.38 V	2.3 Ah	1.51 V	1.9 Ah	1.37 V	1.3 Ah	1.23 V	0.9 Ah	1.16 V
422 A	2.2 Ah	1.39 V	2.4 Ah	1.52 V	2.0 Ah	1.39 V	1.3 Ah	1.22 V	1.0 Ah	1.18 V
423 A	2.2 Ah	1.38 V	2.4 Ah	1.51 V	2.0 Ah	1.38 V	1.5 Ah	1.22 V	1.0 Ah	1.18 V
Average	2.2 Ah	1.38 V	2.4 Ah	1.51 V	2.0 Ah	1.38 V	1.5 Ah	1.23 V	0.9 Ah	1.16 V

their respective code to indicate that the tests are carried out on repeat cells of the same design.

Automatic Cycling

The data are presented in Tables XXXVII to XLI. The status of each cell at the end of the program is also indicated.

Control Group B and Combinations 5 through 12

This category used the separator 3420-25. The manual deep cycles presented in Tables XLII through L give mixed results. As these cells were the first built with the rigid separator 3420-25, the charge regime of constant current to a cut-off voltage of 2.10 V appeared to be excessive for this separator (it is known that zinc penetration is promoted by overcharge). Consequently, about half of the cells shorted between two and five cycles. The cells that reached five cycles safely were not considered worth placing on automatic cycling.

Combinations No. 13 to 20

In this category, the fabrication reverted to the separator 3420-09.

Manual Cycling

The data of the manual deep cycles are presented in Tables LI through LVIII.

Automatic Cycling

The data are presented in Tables LIX through LXVI with the status of each cycling cell at the end of the program.

Failure Analysis

The zinc electrode degradation is due to two factors — loss of active material with cycling, and reduction of efficiency of the overall electrode material. It was, therefore, necessary to determine the extent of each one.

The physical loss of active material was determined by comparing the original weight with the final weight after the cell had failed. All weights were compared on a ZnO basis. The percentage (ζ%) of residual active material was thus computed.

TABLE XXXVII

TEST DATA ON SERIES A

Control Electrode

Cell No.	Regime 1			Regime 2			Regime 3		
	A-11	A-12	A-13	A-21	A-22	A-23	A-31	A-32	A-33
Capacity Checks									
1. N(Q)	107 (1.0)	107 (1.5)	107 (1.7)	104 (1.1)	104 (0.8)	104 (0.9)	28 (2.0)	28 (2.0)	28 (2.1)
2. N(Q)	205 (0.2)	205 (0.5)	205 (0.4)	204 (0.7)	204 (0.5)	204 (0.7)	58 (1.0)	60 (1.2)	63 (1.4)
3. N(Q)		303 (0.2)	302 (0.2)	308 (0.6)	307 (0.5)	307 (0.6)			
4. N(Q)				403 (0.8)	402 (0.6)	402 (0.8)			
5. N(Q)				503 (0.6)	502 (0.4)	502 (0.4)			
6. N(Q)				598 (0.6)					
Status Cycle	236	303	302	598	502	502	58	60	63
Failure Mode	TF	TF	TF	(+)	TF	TF	TF	TF	TF

TF = Technical Failure – Cell cannot deliver the cycling requirement output on a capacity check.

CF = Catastrophic Failure – Cell cannot accept charge or cycle.

N(Q) = Cycle Number (Capacity)

(+) = Cell still cycling at end of program.

TABLE XXXVIII

TEST DATA ON COMBINATION NO. 1

Cell No.	Regime 1			Regime 2			Regime 3		
	111A	112A	113A	121A	122A	123A	131	132	133
Capacity Checks									
1. N(Q)	100 (1.2)	100 (1.1)	100 (1.1)	101 (1.4)	101 (1.2)	101 (1.3)	31 (1.7)	31 (1.7)	31 (1.7)
2. N(Q)	199 (1.4)	199 (1.4)	199 (1.4)	201 (1.5)	199 (1.3)	193 (1.4)	60 (2.0)	38 (1.5)	60 (1.7)
3. N(Q)	299 (1.2)	299 (0.4)	299 (0.4)	303 (1.4)	301 (1.4)	295 (1.1)	88 (2.1)	46 (1.4)	88 (1.8)
4. N(Q)	400 (0.6)	400 (0.4)	400 (0.4)	403 (0.6)	401 (0.5)	393 (0.6)	118 (1.4)		124 (1.6)
5. N(Q)	498 (0.1)	500 (0.1)	500 (0.2)	503 (0.5)	501 (0.6)	492 (0.8)			
6. N(Q)				591 (0.4)	606 (0.7)	592 (0.4)			
7. N(Q)					635 (0.5)				
Status Cycle	498	500	500	591	635	592	118	46	124
Failure Mode	TF	TF	TF	TF	TF	TF	TF	TF	(+)

TF = Technical Failure – Cell cannot deliver the cycling requirement output on a capacity check.

CF = Catastrophic Failure – Cell cannot accept charge or cycle.

N(Q) = Cycle Number (Capacity)

(+) = Cell still cycling at end of program.

TABLE XXXIX

TEST DATA ON COMBINATION NO. 2

Cell No.	Regime 1			Regime 2			Regime 3		
	211A	212A	213A	221A	222A	223A	231	232	233
Capacity Checks									
1. N(Q)	100 (1.9)	100 (1.7)	100 (1.9)	79 (1.5)	101 (1.5)	100 (1.2)	31 (1.7)	31 (1.7)	31 (1.6)
2. N(Q)	199 (1.9)	199 (1.7)	199 (1.8)	101 (1.5)	203 (1.4)	202 (0.7)	60 (1.8)	51 (1.5)	53 (1.7)
3. N(Q)	299 (0.5)	299 (0.2)	299 (0.5)	194 (1.1)	306 (1.1)	301 (0.8)	90 (1.4)	60 (1.5)	60 (1.5)
4. N(Q)	400 (0.4)		400 (0.3)	297 (0.9)	406 (0.6)	400 (1.0)			71 (1.4)
5. N(Q)	499 (0.2)		500 (0.2)	397 (0.5)	495 (0.9)	500 (0.5)			
6. N(Q)				486 (0.8)	595 (0.8)				
7. N(Q)				586 (0.5)	687 (0.5)				
Status Cycle	499	299	500	629	687	500	90	62	71
Failure Mode	TF	TF	TF	TF	TF	TF	TF	TF	TF

TF = Technical Failure – Cell cannot deliver the cycling requirement output on a capacity check.

CF = Catastrophic Failure – Cell cannot accept charge or cycle.

N(Q) = Cycle Number (Capacity)

TABLE XL

TEST DATA ON COMBINATION NO. 3

Cell No.	Regime 1			Regime 2			Regime 3		
	311A	312A	313A	321A	322A	323A	331	332	333
Capacity Checks									
1. N(Q)	100 (1.1)	97 (1.1)	100 (1.2)	73 (1.5)	77 (1.3)	101 (1.1)	31(1.7)	31 (1.5)	31 (1.7)
2. N(Q)	199 (1.7)	199 (1.7)	199 (1.5)	101 (1.5)	101 (1.3)	193 (1.4)	60(1.8)	36 (1.4)	57 (1.4)
3. N(Q)	299 (0.6)	299 (0.4)	299 (0.2)	190 (1.5)	190 (1.4)	294 (1.4)	91(1.5)		
4. N(Q)	388 (0.4)	388 (0.3)		291 (1.1)	288 (1.4)	398 (0.6)	121(1.3)		
5. N(Q)	487 (0)	487 (0)		395 (0.7)	392 (0.6)	498 (1.0)			
6. N(Q)				495 (0.9)	492 (0.8)	598 (0.5)			
7. N(Q)				594 (0.5)	593 (0.4)				
Status Cycle	487	487	299	594	593	630	121	36	57
Failure Mode	CF	CF	TF	TF	TF	TF	TF	TF	TF

TF = Technical Failure – Cell cannot deliver the cycling requirement output on a capacity check.

CF = Catastrophic Failure – Cell cannot accept charge or cycle.

N(Q) = Cycle Number (Capacity)

TABLE XLI

TEST DATA ON COMBINATION NO. 4

Cell No.	Regime 1			Regime 2			Regime 3		
	411A	412A	413A	421A	422A	423A	431	432	433
Capacity Checks									
1. N(Q)	100 (2.1)	100 (1.7)	100 (1.9)	101 (1.6)	101 (1.4)	101 (1.0)	31 (1.7)	31 (1.7)	31 (1.7)
2. N(Q)	199 (1.6)	199 (1.1)	199 (1.5)	203 (1.0)	203 (1.2)	198 (0.9)	33 (1.8)	38 (1.7)	50 (1.4)
3. N(Q)	286 (0)	299 (0.1)	299 (0.2)	302 (0.6)	303 (0.6)	297 (0.6)	42 (1.6)	45 (1.6)	
4. N(Q)				402 (0.5)	403 (0.5)	395 (0.6)	52 (1.5)	48 (1.4)	
5. N(Q)				493 (0.8)	493 (1.0)	485 (0.8)			
6. N(Q)				581 (0.4)	594 (0.6)	570 (0.5)			
7. N(Q)					656 (0.4)				
Status Cycle	286	299	299	581	656	570	52	48	50
Failure Mode	CF	TF	TF	TF	TF	TF	TF	TF	TF

TF = Technical Failure – Cell cannot deliver the cycling requirement output on a capacity check.

CF = Catastrophic Failure – Cell cannot accept charge or cycle.

N(Q) = Cycle Number (Capacity)

TABLE XLII

PRECYCLING TEST DATA

Control Group B (3420-25)

Cell Number	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage
B-11	2.1 Ah	1.44 V	2.5 Ah	1.52 V	2.0 Ah	1.45 V	1.8 Ah	1.37 V	1.8 Ah	1.27 V
B-12	2.0 Ah	1.44 V	2.5 Ah	1.52 V	2.0 Ah	1.44 V	1.6 Ah	1.36 V	1.4 Ah	1.26 V
B-13	2.1 Ah	1.44 V	2.5 Ah	1.52 V	2.0 Ah	1.43 V	1.6 Ah	1.34 V	1.4 Ah	1.24 V
B-21	2.1 Ah	1.44 V	2.5 Ah	1.52 V	1.8 Ah	1.43 V	1.6 Ah	1.33 V	1.6 Ah	1.25 V
B-22	2.1 Ah	1.44 V	2.5 Ah	1.52 V	2.0 Ah	1.45 V	1.8 Ah	1.36 V	1.6 Ah	1.27 V
B-23	2.0 Ah	1.44 V	2.5 Ah	1.52 V	1.8 Ah	1.43 V	1.6 Ah	1.33 V	1.4 Ah	1.24 V
B-31	2.0 Ah	1.44 V	2.5 Ah	1.52 V	1.6 Ah	1.41 V	1.6 Ah	1.33 V	1.2 Ah	1.23 V
B-32	2.0 Ah	1.44 V	2.6 Ah	1.52 V	1.9 Ah	1.43 V	1.6 Ah	1.34 V	1.4 Ah	1.25 V
B-33	2.1 Ah	1.44 V	2.5 Ah	1.52 V	2.0 Ah	1.43 V	1.9 Ah	1.36 V	1.5 Ah	1.26 V
Average	2.1 Ah	1.44 V	2.5 Ah	1.52 V	1.9 Ah	1.43 V	1.7 Ah	1.34 V	1.4 Ah	1.25 V

TABLE XLIII

PRECYCLING TEST DATA

Combination No. 5

Cell Number	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage
511	2.1 Ah	1.42 V	2.4 Ah	1.51 V	1.8 Ah	1.43 V	1.6 Ah	1.36 V	1.4 Ah	1.24 V
512*	2.2 Ah	1.43 V	2.4 Ah	1.51 V	1.7 Ah	1.43 V	1.7 Ah	1.37 V	1.5 Ah	1.24 V
513*	2.3 Ah	1.44 V	2.3 Ah	1.51 V	2.0 Ah	1.43 V	2.1 Ah	1.37 V	1.7 Ah	1.23 V
521	2.2 Ah	1.44 V	2.3 Ah	1.51 V	2.1 Ah	1.44 V	2.0 Ah	1.39 V	1.8 Ah	1.25 V
522*	2.2 Ah	1.43 V	2.3 Ah	1.51 V	1.7 Ah	1.43 V	1.5 Ah	1.36 V	*	
523	2.2 Ah	1.44 V	2.3 Ah	1.51 V	1.9 Ah	1.44 V	1.7 Ah	1.37 V	0.6 Ah	1.20 V
531*	2.0 Ah	1.44 V	2.4 Ah	1.51 V	2.0 Ah	1.44 V	2.0 Ah	1.37 V	1.7 Ah	1.25 V
532	2.2 Ah	1.44 V	2.4 Ah	1.51 V	1.7 Ah	1.44 V	1.6 Ah	1.39 V	1.1 Ah	1.24 V
533*	2.2 Ah	1.45 V	2.4 Ah	1.51 V	*					
Average	2.2 Ah	1.44 V	2.3 Ah	1.51 V	1.9 Ah	1.44 V	1.8 Ah	1.37 V	1.4 Ah	1.24 V

* Failed on recharge at indicated cycle or after last cycle.

TABLE XLIV

PRECYCLING TEST DATA

Combination No. 6

Cell Number	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage
611*	2.2 Ah	1.44 V	2.4 Ah	1.52 V	1.6 Ah	1.42 V	1.1 Ah	1.35 V	*	
612*	2.1 Ah	1.44 V	2.5 Ah	1.52 V	1.6 Ah	1.42 V	1.3 Ah	1.34 V	0.9 Ah	1.21 V
613	2.1 Ah	1.44 V	2.5 Ah	1.52 V	1.7 Ah	1.42 V	1.1 Ah	1.32 V	0.8 Ah	1.20 V
621*	2.2 Ah	1.44 V	2.4 Ah	1.52 V	1.5 Ah	1.41 V	1.4 Ah	1.34 V	*	
622*	2.2 Ah	1.45 V	2.3 Ah	1.52 V	1.7 Ah	1.42 V	1.3 Ah	1.34 V	*	
623*	2.1 Ah	1.41 V	2.4 Ah	1.52 V	1.9 Ah	1.43 V	1.3 Ah	1.35 V	*	
631*	2.1 Ah	1.44 V	2.4 Ah	1.52 V	1.8 Ah	1.42 V	1.3 Ah	1.35 V	*	
632	2.2 Ah	1.40 V	2.4 Ah	1.51 V	1.8 Ah	1.43 V	1.2 Ah	1.35 V	*	
633	2.1 Ah	1.44 V	2.5 Ah	1.52 V	1.8 Ah	1.44 V	1.4 Ah	1.30 V	0.9 Ah	1.22 V
Average	2.2 Ah	1.43 V	2.4 Ah	1.52 V	1.7 Ah	1.42 V	1.3 Ah	1.34 V	0.9 Ah	1.21 V

* Failed on recharge at indicated cycle or after last cycle.

TABLE XLV

PRECYCLING TEST DATA

Combination No. 7

Cell Number	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage
711	2.3 Ah	1.44 V	2.3 Ah	1.51 V	2.1 Ah	1.44 V	1.7 Ah	1.36 V	1.7 Ah	1.20 V
712	2.3 Ah	1.45 V	2.3 Ah	1.51 V	2.1 Ah	1.44 V	2.0 Ah	1.37 V	1.7 Ah	1.22 V
713	2.3 Ah	1.44 V	2.3 Ah	1.51 V	2.0 Ah	1.44 V	1.4 Ah	1.26 V	0.8 Ah	1.18 V
721	2.3 Ah	1.45 V	2.3 Ah	1.51 V	1.8 Ah	1.44 V	1.2 Ah	1.30 V	1.1 Ah	1.20 V
722	2.3 Ah	1.44 V	2.3 Ah	1.51 V	1.8 Ah	1.44 V	1.5 Ah	1.33 V	1.2 Ah	1.21 V
723	2.3 Ah	1.44 V	2.3 Ah	1.51 V	2.0 Ah	1.44 V	1.5 Ah	1.32 V	1.4 Ah	1.21 V
731	2.3 Ah	1.45 V	2.3 Ah	1.51 V	1.9 Ah	1.44 V	1.4 Ah	1.34 V	0.5 Ah	1.20 V
732	2.3 Ah	1.45 V	2.3 Ah	1.51 V	2.1 Ah	1.44 V	1.8 Ah	1.36 V	1.6 Ah	1.22 V
733	2.3 Ah	1.45 V	2.4 Ah	1.51 V	1.9 Ah	1.46 V	1.9 Ah	1.39 V	1.3 Ah	1.20 V
Average	2.3 Ah	1.45 V	2.3 Ah	1.51 V	2.0 Ah	1.44 V	1.6 Ah	1.34 V	1.3 Ah	1.21 V

TABLE XLVI

PRECYCLING TEST DATA

Combination No. 8

Cell Number	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage
811*	2.2 Ah	1.45 V	2.4 Ah	1.53 V	*					
812*	2.1 Ah	1.45 V	2.4 Ah	1.53 V	*					
813*	2.2 Ah	1.45 V	2.4 Ah	1.53 V	1.4 Ah	1.43 V	1.1 Ah	1.25 V	*	
821*	2.0 Ah	1.46 V	2.4 Ah	1.52 V	*					
822*	2.3 Ah	1.45 V	2.4 Ah	1.52 V	1.5 Ah	1.43 V	1.1 Ah	1.22 V	*	
823*	2.3 Ah	1.45 V	2.4 Ah	1.53 V	1.7 Ah	1.43 V	1.2 Ah	1.30 V	*	
831*	2.2 Ah	1.46 V	2.4 Ah	1.53 V	1.5 Ah	1.44 V	1.1 Ah	1.21 V	*	
832*	2.3 Ah	1.45 V	2.2 Ah	1.53 V	1.7 Ah	1.43 V	1.7 Ah	1.36 V	*	
833*	2.1 Ah	1.44 V	2.4 Ah	1.53 V	1.8 Ah	1.46 V	1.4 Ah	1.38 V	*	
Average	2.2 Ah	1.45 V	2.4 Ah	1.53 V	1.6 Ah	1.44 V	1.3 Ah	1.29 V		

* Failed on recharge at indicated cycle or after last cycle.

TABLE XLVII

PRECYCLING TEST DATA

Combination No. 9

Cell Number	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage
911	1.9 Ah	1.40 V	2.6 Ah	1.52 V	1.9 Ah	1.45 V	2.0 Ah	1.36 V	1.5 Ah	1.21 V
912*	1.3 Ah	1.40 V	2.8 Ah	1.51 V	2.1 Ah	1.44 V	2.0 Ah	1.37 V	*	
913	1.7 Ah	1.38 V	2.7 Ah	1.51 V	1.4 Ah	1.44 V	1.4 Ah	1.31 V	1.1 Ah	1.24 V
921*	1.8 Ah	1.42 V	2.7 Ah	1.52 V	1.8 Ah	1.45 V	*			
922*	2.0 Ah	1.41 V	2.6 Ah	1.52 V	2.0 Ah	1.45 V	*			
923	1.8 Ah	1.42 V	2.8 Ah	1.52 V	1.8 Ah	1.45 V	1.2 Ah	1.26 V	0.9 Ah	1.20 V
931	1.7 Ah	1.38 V	2.7 Ah	1.52 V	1.8 Ah	1.45 V	1.5 Ah	1.28 V	0.9 Ah	1.21 V
932*	1.2 Ah	1.40 V	2.7 Ah	1.52 V	2.0 Ah	1.44 V	2.2 Ah	1.37 V	*	
933	1.9 Ah	1.42 V	2.7 Ah	1.52 V	1.7 Ah	1.44 V	1.1 Ah	1.25 V	1.0 Ah	1.22 V
Average	1.7 Ah	1.40 V	2.7 Ah	1.52 V	1.8 Ah	1.44 V	1.6 Ah	1.30 V	1.1 Ah	1.22 V

* Failed on recharge at indicated cycle or after last cycle.

TABLE XLVIII

PRECYCLING TEST DATA

Combination No. 10

Cell Number	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage
1011*	1.9 Ah	1.41 V	2.5 Ah	1.52 V	1.4 Ah	1.44 V	2.1 Ah	1.38 V	*	
1012	2.0 Ah	1.42 V	2.6 Ah	1.51 V	2.0 Ah	1.45 V	2.0 Ah	1.38 V	1.8 Ah	1.28 V
1013	1.9 Ah	1.43 V	2.6 Ah	1.52 V	2.0 Ah	1.45 V	2.3 Ah	1.38 V	2.0 Ah	1.27 V
1021	1.9 Ah	1.41 V	2.6 Ah	1.52 V	2.0 Ah	1.45 V	2.3 Ah	1.38 V	1.9 Ah	1.27 V
1022	1.8 Ah	1.41 V	2.8 Ah	1.51 V	2.0 Ah	1.45 V	2.3 Ah	1.38 V	2.0 Ah	1.28 V
1023	2.0 Ah	1.41 V	2.6 Ah	1.52 V	1.6 Ah	1.45 V	*			
1031*	2.1 Ah	1.40 V	2.8 Ah	1.51 V	1.9 Ah	1.45 V	2.0 Ah	1.37 V	*	
1032*	1.9 Ah	1.42 V	2.6 Ah	1.52 V	1.9 Ah	1.45 V	2.1 Ah	1.39 V	*	
1033	2.0 Ah	1.42 V	2.5 Ah	1.52 V	1.8 Ah	1.45 V	*			
Average	1.9 Ah	1.41 V	2.6 Ah	1.52 V	1.9 Ah	1.45 V	2.2 Ah	1.38 V	1.9 Ah	1.28 V

* Failed on recharge after indicated cycle or last cycle.

TABLE IL

PRECYCLING TEST DATA

Combination No. 11

Cell Number	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage
1111*	2.1 Ah	1.44 V	2.5 Ah	1.53 V	1.9 Ah	1.45 V	*			
1112*	2.3 Ah	1.44 V	2.5 Ah	1.52 V	2.3 Ah	1.45 V	*			
1113	2.2 Ah	1.44 V	2.4 Ah	1.52 V	2.1 Ah	1.45 V	2.2 Ah	1.39 V	1.6 Ah	1.26 V
1121*	2.1 Ah	1.44 V	2.5 Ah	1.52 V	2.1 Ah	1.45 V	*			
1122*	2.1 Ah	1.44 V	2.5 Ah	1.52 V	2.1 Ah	1.45 V	1.7 Ah	1.38 V	*	
1123	2.3 Ah	1.45 V	2.5 Ah	1.52 V	2.3 Ah	1.45 V	2.2 Ah	1.38 V	1,5 Ah	1.26 V
1131*	2.2 Ah	1.44 V	2.5 Ah	1.52 V	2.0 Ah	1.45 V	1.7 Ah	1.37 V	*	
1132*	2.1 Ah	1.44 V	2.6 Ah	1.52 V	1.8 Ah	1.45 V	*			
1133*	2.1 Ah	1.44 V	2.4 Ah	1.52 V	2.3 Ah	1.45 V	*			
Average	2.2 Ah	1.44 V	2.5 Ah	1.52 V	2.1 Ah	1.45 V	2.0 Ah	1.38 V	1.6 Ah	1.26 V

* Failed on recharge after indicated cycle or last cycle.

TABLE L

PRECYCLING TEST DATA

Combination No. 12

Cell Number	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage	Output	Plateau Voltage
1211	2.1 Ah	1.45 V	2.5 Ah	1.52 V	1.8 Ah	1.43 V	1.4 Ah	1.31 V	1.2 Ah	1.19 V
1212*	2.2 Ah	1.45 V	2.5 Ah	1.53 V	1.4 Ah	1.45 V	*			
1213*	2.1 Ah	1.46 V	2.5 Ah	1.52 V	1.9 Ah	1.45 V	*			
1221*	2.0 Ah	1.45 V	2.4 Ah	1.53 V	1.6 Ah	1.46 V	1.1 Ah	1.23 V	*	
1222*	2.2 Ah	1.45 V	2.5 Ah	1.53 V	1.6 Ah	1.45 V	*			
1223*	2.2 Ah	1.45 V	2.5 Ah	1.53 V	1.8 Ah	1.44 V	1.5 Ah	1.35 V	*	
1231	2.2 Ah	1.46 V	2.5 Ah	1.53 V	1.4 Ah	1.44 V	1.7 Ah	1.34 V	0.9 Ah	1.21 V
1232*	2.3 Ah	1.45 V	2.5 Ah	1.53 V	2.1 Ah	1.44 V	*			
1233*	2.2 Ah	1.45 V	2.5 Ah	1.53 V	1.9 Ah	1.43 V	1.5 Ah	1.32 V	*	
Average	2.2 Ah	1.45 V	2.5 Ah	1.52 V	1.7 Ah	1.44 V	1.4 Ah	1.31 V	1.1 Ah	1.20 V

* Failed on recharge after indicated cycle or last cycle.

TABLE LI

PRECYCLING TEST DATA

Combination No. 13

Cell No.	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)
1311	2.0 Ah	1.40 V	2.4 Ah	1.52 V	1.7 Ah	1.35 V	1.5 Ah	1.25 V	1.1 Ah	1.18 V
1312	2.0 Ah	1.39 V	2.3 Ah	1.52 V	1.7 Ah	1.37 V	1.4 Ah	1.26 V	1.0 Ah	1.19 V
1313	2.1 Ah	1.41 V	2.3 Ah	1.52 V	1.7 Ah	1.37 V	1.5 Ah	1.27 V	1.2 Ah	1.24 V
1321	2.1 Ah	1.41 V	2.5 Ah	1.52 V	1.7 Ah	1.34 V	1.2 Ah	1.26 V	1.1 Ah	1.22 V
1322	2.0 Ah	1.37 V	2.3 Ah	1.52 V	1.5 Ah	1.32 V	1.0 Ah	1.22 V	0.5 Ah	1.12 V
1323	2.1 Ah	1.43 V	2.3 Ah	1.51 V	1.6 Ah	1.37 V	1.2 Ah	1.21 V	1.0 Ah	1.19 V
1331	2.2 Ah	1.43 V	2.3 Ah	1.52 V	1.7 Ah	1.33 V	1.5 Ah	1.24 V	1.1 Ah	1.22 V
1332	2.1 Ah	1.42 V	2.4 Ah	1.52 V	1.6 Ah	1.34 V	1.2 Ah	1.21 V	0.8 Ah	1.15 V
1333	2.2 Ah	1.42 V	2.3 Ah	1.52 V	1.7 Ah	1.35 V	1.2 Ah	1.23 V	1.0 Ah	1.22 V
Avg.	2.1 Ah	1.41 V	2.3 Ah	1.52 V	1.7 Ah	1.36 V	1.3 Ah	1.24 V	1.0 Ah	1.19 V

TABLE LII

PRECYCLING TEST DATA

Combination No. 14

Cell No.	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)
1411	2.1 Ah	1.41 V	2.3 Ah	1.53 V	1.8 Ah	1.38 V	1.5 Ah	1.25 V	1.2 Ah	1.20 V
1412	2.1 Ah	1.42 V	2.3 Ah	1.51 V	1.5 Ah	1.35 V	1.2 Ah	1.21 V	1.0 Ah	1.17 V
1413	2.1 Ah	1.41 V	2.3 Ah	1.52 V	1.7 Ah	1.40 V	1.4 Ah	1.23 V	1.1 Ah	1.17 V
1421	2.1 Ah	1.42 V	2.3 Ah	1.53 V	1.5 Ah	1.32 V	1.1 Ah	1.18 V	0.9 Ah	1.12 V
1422	1.7 Ah	1.32 V	2.4 Ah	1.51 V	1.7 Ah	1.38 V	1.4 Ah	1.21 V	0.8 Ah	1.11 V
1423	1.8 Ah	1.37 V	2.4 Ah	1.52 V	1.5 Ah	1.33 V	1.2 Ah	1.22 V	1.0 Ah	1.13 V
1431	2.0 Ah	1.39 V	2.3 Ah	1.52 V	1.7 Ah	1.40 V	1.5 Ah	1.25 V	1.1 Ah	1.16 V
1432	2.0 Ah	1.41 V	2.3 Ah	1.52 V	1.7 Ah	1.36 V	1.5 Ah	1.24 V	1.2 Ah	1.17 V
1433	2.0 Ah	1.38 V	2.3 Ah	1.51 V	1.5 Ah	1.35 V	1.2 Ah	1.22 V	0.9 Ah	1.13 V
Avg.	2.0 Ah	1.39 V	2.3 Ah	1.52 V	1.6 Ah	1.36 V	1.3 Ah	1.22 V	1.0 Ah	1.15 V

TABLE LIII

PRECYCLING TEST DATA

Combination No. 15

Cell No.	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)
1511	2.3 Ah	1.44 V	2.5 Ah	1.54 V	2.0 Ah	1.41 V	1.1 Ah	1.27 V	0.7 Ah	1.09 V
1512	2.3 Ah	1.43 V	2.5 Ah	1.54 V	1.8 Ah	1.39 V	1.2 Ah	1.28 V	0.9 Ah	1.17 V
1513	2.3 Ah	1.42 V	2.5 Ah	1.54 V	2.1 Ah	1.40 V	1.7 Ah	1.30 V	1.2 Ah	1.15 V
1521	2.2 Ah	1.43 V	2.5 Ah	1.53 V	2.0 Ah	1.41 V	1.2 Ah	1.28 V	0.9 Ah	1.10 V
1522	2.1 Ah	1.43 V	2.6 Ah	1.54 V	1.8 Ah	1.39 V	1.1 Ah	1.29 V	0.9 Ah	1.14 V
1523	2.3 Ah	1.43 V	2.4 Ah	1.54 V	2.1 Ah	1.41 V	1.9 Ah	1.31 V	1.5 Ah	1.20 V
1531	2.2 Ah	1.42 V	2.5 Ah	1.54 V	2.1 Ah	1.41 V	1.7 Ah	1.33 V	1.2 Ah	1.17 V
1532	2.2 Ah	1.44 V	2.5 Ah	1.54 V	1.9 Ah	1.40 V	1.2 Ah	1.32 V	1.0 Ah	1.16 V
1533	2.1 Ah	1.42 V	2.6 Ah	1.54 V	2.0 Ah	1.40 V	1.5 Ah	1.32 V	1.0 Ah	1.18 V
Avg.	2.3 Ah	1.43 V	2.5 Ah	1.54 V	2.0 Ah	1.40 V	1.4 Ah	1.30 V	1.0 Ah	1.15 V

TABLE LIV

PRECYCLING TEST DATA

Combination No. 16

Cell No.	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)
1611	2.1 Ah	1.44 V	2.6 Ah	1.55 V	1.9 Ah	1.42 V	1.4 Ah	1.38 V	1.0 Ah	1.21 V
1612	2.1 Ah	1.44 V	2.5 Ah	1.54 V	1.8 Ah	1.42 V	1.4 Ah	1.34 V	1.0 Ah	1.16 V
1613	2.1 Ah	1.42 V	2.6 Ah	1.55 V	2.0 Ah	1.42 V	1.2 Ah	1.33 V	1.0 Ah	1.16 V
1621	2.1 Ah	1.43 V	2.6 Ah	1.54 V	1.9 Ah	1.43 V	1.4 Ah	1.34 V	1.1 Ah	1.19 V
1622	2.1 Ah	1.43 V	2.5 Ah	1.55 V	1.7 Ah	1.40 V	1.2 Ah	1.30 V	0.9 Ah	1.14 V
1623	2.1 Ah	1.43 V	2.5 Ah	1.55 V	1.8 Ah	1.42 V	1.1 Ah	1.34 V	0.9 Ah	1.17 V
1631	2.2 Ah	1.44 V	2.5 Ah	1.55 V	1.8 Ah	1.42 V	1.2 Ah	1.35 V	0.9 Ah	1.14 V
1632	2.2 Ah	1.45 V	2.5 Ah	1.55 V	2.0 Ah	1.43 V	1.5 Ah	1.34 V	1.1 Ah	1.17 V
1633	2.1 Ah	1.44 V	2.6 Ah	1.55 V	2.0 Ah	1.43 V	1.2 Ah	1.38 V	1.0 Ah	1.20 V
Avg.	2.1 Ah	1.44 V	2.5 Ah	1.55 V	1.9 Ah	1.42 V	1.3 Ah	1.34 V	1.0 Ah	1.17 V

TABLE LV

PRECYCLING TEST DATA

Combination No. 17

Cell No.	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)
1711	2.0 Ah	1.39 V	2.3 Ah	1.51 V	2.0 Ah	1.40 V	1.5 Ah	1.32 V	1.2 Ah	1.15 V
1712	2.0 Ah	1.39 V	2.2 Ah	1.52 V	1.9 Ah	1.40 V	1.2 Ah	1.34 V	1.1 Ah	1.16 V
1713	2.2 Ah	1.41 V	2.2 Ah	1.52 V	2.0 Ah	1.41 V	1.5 Ah	1.32 V	1.2 Ah	1.16 V
1721	2.2 Ah	1.40 V	2.3 Ah	1.51 V	2.3 Ah	1.42 V	2.0 Ah	1.34 V	1.4 Ah	1.20 V
1722	2.2 Ah	1.39 V	2.3 Ah	1.52 V	2.0 Ah	1.40 V	1.6 Ah	1.33 V	1.1 Ah	1.17 V
1723	2.3 Ah	1.41 V	2.3 Ah	1.52 V	2.2 Ah	1.42 V	1.8 Ah	1.34 V	1.4 Ah	1.20 V
1731	2.0 Ah	1.40 V	2.3 Ah	1.52 V	2.1 Ah	1.41 V	1.5 Ah	1.34 V	1.2 Ah	1.19 V
1732	2.0 Ah	1.39 V	2.2 Ah	1.52 V	2.0 Ah	1.41 V	1.8 Ah	1.32 V	1.4 Ah	1.16 V
1733	2.2 Ah	1.41 V	2.3 Ah	1.51 V	2.1 Ah	1.41 V	1.6 Ah	1.33 V	1.2 Ah	1.21 V
Avg.	2.1 Ah	1.40 V	2.3 Ah	1.52 V	2.1 Ah	1.41 V	1.6 Ah	1.33 V	1.2 Ah	1.18 V

TABLE LVI

PRECYCLING TEST DATA

Combination No. 18

Cell No.	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)
1811	1.8 Ah	1.38 V	2.3 Ah	1.51 V	1.9 Ah	1.40 V	1.5 Ah	1.35 V	1.1 Ah	1.16 V
1812	1.8 Ah	1.38 V	2.3 Ah	1.52 V	1.8 Ah	1.38 V	1.2 Ah	1.33 V	1.0 Ah	1.15 V
1813	1.7 Ah	1.39 V	2.3 Ah	1.51 V	1.8 Ah	1.37 V	1.2 Ah	1.30 V	0.9 Ah	1.10 V
1821	1.8 Ah	1.40 V	2.3 Ah	1.51 V	1.9 Ah	1.40 V	1.5 Ah	1.32 V	1.0 Ah	1.16 V
1822	1.8 Ah	1.39 V	2.3 Ah	1.51 V	1.8 Ah	1.38 V	1.2 Ah	1.31 V	0.9 Ah	1.12 V
1823	2.0 Ah	1.38 V	2.2 Ah	1.52 V	1.8 Ah	1.39 V	1.2 Ah	1.32 V	1.1 Ah	1.17 V
1831	1.8 Ah	1.38 V	2.3 Ah	1.51 V	1.8 Ah	1.39 V	1.2 Ah	1.32 V	0.9 Ah	1.13 V
1832	2.0 Ah	1.40 V	2.3 Ah	1.51 V	1.9 Ah	1.40 V	1.5 Ah	1.31 V	0.9 Ah	1.14 V
1833	2.1 Ah	1.39 V	2.3 Ah	1.52 V	1.9 Ah	1.39 V	1.2 Ah	1.30 V	1.0 Ah	1.12 V
Avg.	1.9 Ah	1.39 V	2.3 Ah	1.51 V	1.8 Ah	1.39 V	1.3 Ah	1.32 V	1.0 Ah	1.14 V

TABLE LVII

PRECYCLING TEST DATA

Combination No. 19

Cell No.	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)
1911	2.2 Ah	1.44 V	2.3 Ah	1.52 V	2.2 Ah	1.43 V	1.5 Ah	1.32 V	0.9 Ah	1.15 V
1912	2.3 Ah	1.44 V	2.3 Ah	1.52 V	2.3 Ah	1.43 V	1.6 Ah	1.35 V	0.9 Ah	1.14 V
1913	2.3 Ah	1.44 V	2.3 Ah	1.52 V	2.0 Ah	1.43 V	1.8 Ah	1.32 V	0.9 Ah	1.11 V
1921	2.3 Ah	1.45 V	2.2 Ah	1.53 V	2.3 Ah	1.44 V	1.2 Ah	1.29 V	0.9 Ah	1.13 V
1922	2.3 Ah	1.44 V	2.3 Ah	1.53 V	2.2 Ah	1.44 V	1.9 Ah	1.33 V	0.9 Ah	1.13 V
1923	2.3 Ah	1.45 V	2.3 Ah	1.52 V	2.2 Ah	1.44 V	1.8 Ah	1.33 V	0.9 Ah	1.15 V
1931	2.3 Ah	1.44 V	2.2 Ah	1.52 V	2.2 Ah	1.44 V	1.8 Ah	1.32 V	1.0 Ah	1.14 V
1932	2.3 Ah	1.45 V	2.3 Ah	1.52 V	2.2 Ah	1.43 V	1.8 Ah	1.31 V	0.9 Ah	1.11 V
1933	2.3 Ah	1.45 V	2.2 Ah	1.52 V	2.0 Ah	1.44 V	1.8 Ah	1.33 V	1.1 Ah	1.15 V
Avg.	2.3 Ah	1.44 V	2.3 Ah	1.52 V	2.2 Ah	1.44 V	1.7 Ah	1.32 V	0.9 Ah	1.13 V

TABLE LVIII

PRECYCLING TEST DATA

Combination No. 20

Cell No.	Formation (0.6 A)		Cycle 1 (30 mA)		Cycle 2 (0.6 A)		Cycle 3 (1.5 A)		Cycle 4 (3 A)	
	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)	Output (Ah)	Plateau Voltage (V)
2011	2.2 Ah	1.43 V	2.3 Ah	1.53 V	2.3 Ah	1.43 V	1.6 Ah	1.28 V	1.1 Ah	1.12 V
2012	2.2 Ah	1.42 V	2.3 Ah	1.53 V	2.0 Ah	1.42 V	1.9 Ah	1.28 V	1.0 Ah	1.07 V
2013	2.2 Ah	1.43 V	2.3 Ah	1.53 V	2.2 Ah	1.40 V	2.0 Ah	1.29 V	1.0 Ah	1.09 V
2021	2.3 Ah	1.43 V	2.3 Ah	1.53 V	2.2 Ah	1.43 V	2.0 Ah	1.32 V	1.2 Ah	1.15 V
2022	2.3 Ah	1.44 V	2.3 Ah	1.52 V	2.3 Ah	1.45 V	2.1 Ah	1.36 V	1.4 Ah	1.21 V
2023	2.3 Ah	1.44 V	2.3 Ah	1.52 V	2.2 Ah	1.44 V	2.0 Ah	1.34 V	1.4 Ah	1.16 V
2031	2.2 Ah	1.44 V	2.3 Ah	1.52 V	2.1 Ah	1.44 V	1.6 Ah	1.35 V	1.1 Ah	1.18 V
2032	2.2 Ah	1.43 V	2.3 Ah	1.53 V	2.2 Ah	1.42 V	1.9 Ah	1.29 V	1.1 Ah	1.11 V
2033	2.3 Ah	1.43 V	2.3 Ah	1.52 V	2.2 Ah	1.44 V	2.0 Ah	1.32 V	1.2 Ah	1.17 V
Avg.	2.2 Ah	1.43 V	2.3 Ah	1.53 V	2.2 Ah	1.43 V	1.9 Ah	1.31 V	1.2 Ah	1.14 V

TABLE LIX

TEST DATA ON COMBINATION NO. 13

Cell No.	Regime 1			Regime 2			Regime 3		
	1311	1312	1313	1321	1322	1323	1331	1332	1333
Capacity Checks									
1. N(Q)	105 (1.6)	105 (1.6)	105 (1.6)	103 (0.6)	103 (0.8)	103 (0.5)	25 (1.3)	17 (1.2)	23 (1.3)
2. N(Q)	215 (1.4)	215 (1.3)	215 (1.3)	203 (0.4)	204 (0.6)	204 (0.4)			
3. N(Q)	305 (0.6)	305 (0.5)	305 (0.4)		233 (0.7)				
4. N(Q)					270 (0.7)				
5. N(Q)									
6. N(Q)									
Status Cycle	373	373	373	203	270	204	25	17	23
Failure Mode	(+)	(+)	(+)	TF	(+)	TF	TF	TF	TF

TF = Technical Failure – Cell cannot deliver the cycling requirement output on a capacity check.

CF = Catastrophic Failure – Cell cannot accept charge or cycle.

N(Q) = Cycle Number (Capacity)

(+) = Cell still cycling at end of program.

TABLE LX

TEST DATA ON COMBINATION NO. 14

Cell No.	Regime 1			Regime 2			Regime 3		
	1411	1412	1413	1421	1422	1423	1431	1432	1433
Capacity Checks									
1. N(Q)	105 (1.6)	105 (1.7)	105 (2.0)	103 (0.5)	103 (0.7)	103 (0.7)	26 (1.1)	28 (1.1)	23 (0.9)
2. N(Q)	215 (1.4)	215 (1.3)	215 (1.4)	204 (0.5)	204 (0.6)	204 (0.6)			
3. N(Q)	305 (0.6)	305 (0.6)	305 (0.4)	297 (0.5)	298 (0.5)	299 (0.5)			
4. N(Q)									
5. N(Q)									
6. N(Q)									
Status Cycle	373	373	373	297	298	299	26	28	23
Failure Mode	(+)	(+)	(+)	(+)	(+)	(+)	TF	TF	TF

TF = Technical Failure – Cell cannot deliver the cycling requirement output on a capacity check.

CF = Catastrophic Failure – Cell cannot accept charge or cycle.

N(Q) = Cycle Number (Capacity)

(+) = Cell still cycling at end of program.

TABLE LXI

TEST DATA ON COMBINATION NO. 15

Cell No.	Regime 1			Regime 2			Regime 3		
	1511	1512	1513	1521	1522	1523	1531	1532	1533
Capacity Checks									
1. N(Q)	105 (1.6)	105 (1.8)	105 (2.0)	103 (0.6)	103 (0.6)	103 (1.0)	29 (1.3)	21 (0.9)	15 (1.2)
2. N(Q)	215 (1.6)	215 (1.8)	215 (1.8)	122 (0.4)	135 (0.5)	204 (0.7)			
3. N(Q)	305 (0.6)	305 (0.8)	305 (0.8)			283 (0.5)			
4. N(Q)									
5. N(Q)									
6. N(Q)									
Status Cycle	373	373	373	122	135	283	29	21	15
Failure Mode	(+)	(+)	(+)	TF	TF	TF	TF	TF	TF

TF = Technical Failure – Cell cannot deliver the cycling requirement output on a capacity check.

CF = Catastrophic Failure – Cell cannot accept charge or cycle.

N(Q) = Cycle Number (Capacity)

(+) = Cell still cycling at end of program.

TABLE LXII

TEST DATA ON COMBINATION NO. 16

Cell No.	Regime 1			Regime 2			Regime 3		
	1611	1612	1613	1621	1622	1623	1631	1632	1633
Capacity Checks									
1. N(Q)	105 (1.7)	105 (1.4)	105 (1.4)	103 (0.5)	103 (0.5)	103 (0.5)	22 (0.7)	26 (1.1)	15 (1.2)
2. N(Q)	215 (1.2)	215 (1.6)	215 (1.5)	124 (0.4)	123 (0.4)	120 (0.3)			
3. N(Q)	305 (1.2)	305 (0.8)	305 (0.7)						
4. N(Q)									
5. N(Q)									
6. N(Q)									
Status Cycle	373	373	373	124	123	120	22	26	15
Failure Mode	(+)	(+)	(+)	TF	TF	TF	TF	TF	TF

TF = Technical Failure – Cell cannot deliver the cycling requirement output on a capacity check.

CF = Catastrophic Failure – Cell cannot accept charge or cycle.

N(Q) = Cycle Number (Capacity)

(+) = Cell still cycling at end of program.

TABLE LXIII

TEST DATA ON COMBINATION NO. 17

Cell No.	Regime 1			Regime 2			Regime 3		
	1711	1712	1713	1721	1722	1723	1731	1732	1733
Capacity Checks									
1. N(Q)	105 (1.7)	105 (1.4)	105 (1.7)	105 (0.5)	105 (0.5)	105 (0.5)	15 (1.3)	15 (1.6)	15 (1.5)
2. N(Q)	198 (1.3)	198 (1.0)	198 (1.3)	172 (0.4)	171 (0.4)	170 (0.5)			
3. N(Q)									
4. N(Q)									
5. N(Q)									
6. N(Q)									
Status Cycle	266	266	266	172	171	170	15	15	15
Failure Mode	(+)	(+)	(+)	TF	TF	(+)	TF	(+)	(+)

TF = Technical Failure – Cell cannot deliver the cycling requirement output on a capacity check.

CF = Catastrophic Failure – Cell cannot accept charge or cycle.

N(Q) = Cycle Number (Capacity)

(+) = Cell still cycling at end of program.

TABLE LXIV

TEST DATA ON COMBINATION NO. 18

Cell No.	Regime 1			Regime 2			Regime 3		
	1811	1812	1813	1821	1822	1823	1831	1832	1833
Capacity Checks									
1. N(Q)	105 (1.5)	105 (1.4)	105 (1.4)	105 (0.6)	105 (0.6)	105 (0.5)	14 (1.3)	15 (1.3)	12 (1.3)
2. N(Q)	198 (1.0)	198 (0.7)	198 (0.9)	172 (0.5)	172 (0.5)	170 (0.5)			
3. N(Q)									
4. N(Q)									
5. N(Q)									
6. N(Q)									
Status Cycle	266	266	266	172	172	170	14	15	12
Failure Mode	(+)	(+)	(+)	(+)	(+)	(+)	TF	TF	TF

TF = Technical Failure – Cell cannot deliver the cycling requirement output on a capacity check.

CF = Catastrophic Failure – Cell cannot accept charge or cycle.

N(Q) = Cycle Number (Capacity)

(+) = Cell still cycling at end of program.

TABLE LXV

TEST DATA ON COMBINATION NO. 19

Cell No.	Regime 1			Regime 2			Regime 3		
	1911	1912	1913	1921	1922	1923	1931	1932	1933
Capacity Checks									
1. N(Q)	105 (1.2)	105 (1.3)	*	105 (0.6)	105 (0.5)	105 (0.5)	14 (1.2)	15 (1.2)	12 (1.4)
2. N(Q)	198 (0.5)	198 (0.6)		170 (0.4)	157 (0.4)				
3. N(Q)									
4. N(Q)									
5. N(Q)									
6. N(Q)									
Status Cycle	266	266	*	170	157	105	14	15	12
Failure Mode	(+)	(+)	*	TF	TF	TF	TF	TF	TF

TF = Technical Failure – Cell cannot deliver the cycling requirement output on a capacity check.

CF = Catastrophic Failure – Cell cannot accept charge or cycle.

N(Q) = Cycle Number (Capacity)

(+) = Cell still cycling at end of program.

* = Cell failed after five precycling tests; construction deficiency.

TABLE LXVI

TEST DATA ON COMBINATION NO. 20

Cell No.	Regime 1			Regime 2			Regime 3		
	2011	2012	2013	2021	2022	2023	2031	2032	2033
Capacity Checks									
1. N(Q)	105 (1.4)	105 (1.1)	105 (1.2)	105 (0.5)	105 (0.7)	*	14 (1.1)	14 (1.1)	13 (1.4)
2. N(Q)	198 (0.7)	198 (0.3)	198 (0.5)	170 (0.5)	169 (0.4)				
3. N(Q)									
4. N(Q)									
5. N(Q)									
6. N(Q)									
Status Cycle	266	266	266	170	169	*	14	14	13
Failure Mode	(+)	(+)	(+)	(+)	TF	*	TF	TF	TF

TF = Technical Failure – Cell cannot deliver the cycling requirement output on a capacity check.

CF = Catastrophic Failure – Cell cannot accept charge or cycle.

N(Q) = Cycle Number (Capacity)

(+) = Cell still cycling at end of program.

* = Cell failed after five precycling tests; construction deficiency.

The overall electrode efficiency (η%) was determined by computing the percentage of residual capacity (q%) of capacity prior to failure cycle with respect to original capacity and dividing this figure by the residual weight percentage (ζ%) calculated above. This is equivalent to the percentage of the final output per gram with respect to the original output per gram, or the final-to-original utilization ratio in %.

To take into account the composition and the process of the zinc electrode, the efficiency of actual zinc metal present in the electrode was determined immediately after charge on the first and second cycles. It was done on two cells using unsintered zinc oxide electrodes and two cells using sintered 90/10 Z mix electrodes. Table LXVII giving the results of the four cells shows that the zinc utilization is in the range of 86% over two cycles, regardless of the mix. It can be postulated that adding an inorganic material and sintering the mix at 850°C have no significant effect on the zinc utilization efficiency.

The dissection, examination, and analysis of failed cells was done on one cell of each group (covering a specific combination and a specific test regime). The data of all cells examined prior to the end of the program are presented in detail in Appendix B. A summary of the pertinent information is given in Tables LXVIII, LXIX, and LXX.

Data Evaluation

Although the cycling test data were not complete by the end of the program period, an evaluation may be attempted. Disregarding all combinations 5 through 12 because they used another separator type (3420-25), we shall compare control group A and the other combinations. Most of the data were acquired on group A and combinations 1 to 4. Their average number of cycles are presented in Table LXXI. It appears that combination #1 has more cycles on all three regimes than control group A; combinations #2 and #3 show also better averages, although marginal on regime #3; combination #4 is marginal on all regimes. This shows at least that the 90/10 Z mix, common to all, must be a contributing factor toward improving the electrode. From the cycling data and the failure analyses, it seems also that the Exmet grid has a slight advantage over the Distex grid, although the electrode using a Distex grid has a better shape retention throughout its cycle life. The encapsulated positive design appears also to be beneficial to longer cycle life.

An analysis of variances was performed on control group A and experimental groups 1 through 4. The following conclusions were drawn:

(a) Each test regime datum must be analyzed independently.

TABLE LXVII

ZINC UTILIZATION

Mix	Cell No.	Original ZnO Weight (g)	Cycle No.	Total Output (Ah)	Charged Zinc (g)	Zinc	
						Utilization (Ah/g)	Efficiency* (%)
100% ZnO	ZN-47-1	5.88	1	2.0	2.90	0.69	84
	ZN-47-2	5.88	2	2.2	3.18	0.69	84
90/10 Z	ZN-47-3	5.40	1	2.0	2.84	0.70	85
	ZN-47-4	5.40	2	2.2	3.04	0.72	89

*With respect to theoretical.

TABLE LXVIII

CELL ANALYSIS SUMMARY

Regime No. 1 = 100°C, Discharge 0.60 A for 0.5 hr
Charge 0.66 A for 0.5 hr

Identification			Electrical Characteristics					ZnO Content			Final-to-Original Utilization Ratio (%)
Combination	Cell Code	Mix and Process	Original Qo (Ah)	Wet Life (days)	Cycles N	Final Q (Ah)	Residual Capacity (%)	Original (g)	Final (g)	Residual ζ (%)	
A	A-13	Control	2.0	65	302	0.2	10	5.9	3.6	61	16
1	112A	90/10-Z, N	2.0	90	500	0.1	5	5.4	2.0	37	14
2	212A	↓	2.1	60	299	0.2	10	↓	3.4	63	16
3	313A	↓	2.1	60	299	0.2	10	↓	2.5	46	22
4	412A	↓	2.1	57	299	0.1	5	↓	2.7	50	10
13	1311	↓	2.0	53	373*	0.6	33	↓	3.2	59	56
14	1411	↓	2.1	53	373*	0.6	35	↓	3.1	57	61
15	1512	90/10-Z, PS	2.3	53	373*	0.8	35	↓	3.3	61	57
16	1611	"	2.1	49	373*	1.2	57	↓	3.3	61	94
17	1711	80/20-Z, N	2.0	47	266*	1.3	65	4.8	2.7	56	100
18	1811	"	1.8	47	266*	1.0	56	↓	2.7	56	100
19	1912	80/20-Z, PS	2.3	47	266*	0.6	38	↓	2.6	54	70
20	2011	"	2.2	47	266*	0.7	32	↓	2.6	54	59

*Not failed.

TABLE LXIX

CELL ANALYSIS SUMMARY

Regime No. 2 = 25°C, Discharge 0.90 A for 0.5 hr
Charge 0.50 A for 1.0 hr

Identification			Electrical Characteristics					ZnO Content			Final-to-Original Utilization Ratio (%)
Combination	Cell Code	Mix and Process	Original Qo (Ah)	Wet Life (days)	Cycles N	Final Q (Ah)	Residual Capacity (%)	Original (g)	Final (g)	Residual ξ (%)	
A	A-22	Control	2.0	96	502	0.4	20	5.9	4.5	76	26
1	123A	90/10-Z, N	2.0	114	591	0.4	20	5.4	3.7	69	29
2	223A	↓	2.0	86	500	0.5	25	↓	3.9	72	35
3	322A	↓	2.1	114	593	0.4	19	↓	3.9	72	26
4	421A	↓	2.2	114	581	0.4	18	↓	4.0	74	24
13	1321	↓	2.1	41	203	0.4	19	↓	3.6	67	28
14	1422	↓	1.7	53	298*	0.5	29	↓	3.6	67	43
15	1521	90/10-Z, PS	2.2	34	122	0.4	18	↓	3.8	70	26
16	1621	"	2.1	30	124	0.4	19	↓	3.6	67	28
17	1722	80/20-Z, N	2.2	47	170	0.4	18	4.8	2.8	58	31
18	1822	"	1.8	47	172*	0.5	28	↓	3.0	62	45
19	1923	80/20-Z, PS	2.3	40	105	0.5	22	↓	3.1	65	34
20	2022	"	2.3	47	169	0.4	17	↓	2.6	54	31

*Not failed.

TABLE LXX

CELL ANALYSIS SUMMARY

Regime No. 3 = 25°C, Discharge 1.20 A for 1.2 hr
Charge 0.07 A for 22.8 hr

Identification			Electrical Characteristics					ZnO Content			Final-to-Original Utilization Ratio (%)
Combination	Cell Code	Mix and Process	Original Qo (Ah)	Wet Life (days)	Cycles N	Final Q (Ah)	Residual Capacity (%)	Original (g)	Final (g)	Residual ζ (%)	
A	A-32	Control	2.0	107	60	1.2	60	5.9	4.8	81	74
1	132	90/10-Z, N	2.3	90	46	1.4	61	5.4	3.7	69	88
1	131	↓	2.3	184	118	1.4	61	↓	3.5	65	94
2	232	↓	2.3	111	62	1.5	65	↓	3.9	72	90
3	332	↓	2.3	111	36	1.4	61	↓	3.9	72	85
4	431	↓	2.3	90	52	1.5	65	↓	4.0	74	88
13	1332	↓	2.1	34	17	1.2	57	↓	3.9	72	79
14	1431	↓	2.0	53	26	1.1	61	↓	4.6	85	72
15	1533	90/10-Z, PS	2.1	34	15	1.2	57	↓	4.0	74	77
16	1633	"	2.1	30	15	1.2	57	↓	4.2	78	73
17	1731	80/20-Z, N	2.0	47	15	1.3	65	4.8	3.7	77	84
18	1831	"	1.8	47	14	1.3	72	↓	3.9	81	89
19	1931	80/20-Z, PS	2.3	47	14	1.2	52	↓	4.0	83	63
20	2032	"	2.2	47	14	1.1	50	↓	3.8	79	63

TABLE LXXI

NUMBER OF CYCLES REACHED ON EACH REGIME

(Average of 3 Cells)

Combination No.	Regime 1	Regime 2	Regime 3
A	280	534	60
1	500	606	96*
2	433	605	74
3	424	606	71
4	295	602	50
13	373*	226*	22
14	373*	298*	26
15	373*	180	22
16	373*	122	21
17	266*	171*	15*
18	266*	172*	14
19	266*	144	14
20	266*	170*	14

*Cells still cycling at the end of the program period.

(b) The factors studied (grid structure, wafer design) were significant for test regime #1, but not for regimes #2 and #3.

(c) On test regime #1, cells of combination 4 were as good as the control cells, but poorer than cells of any other construction.

The data on all other combinations were not far enough advanced at the end of the program to be fully conclusive. However, the following trends can be noticed:

(a) Introduction of lead did not seem to help on regime #3.

(b) The presintered (PS) process seems less advantageous than the normal (N) process. Combinations #15 and #16 reached about 150 cycles contrasted to #13 and #14 which reached about 250 cycles on regime #2.

A very important facet of this evaluation is that all the test cells were zinc limited and consequently possibly overcharged, since they were cycled in series and they might have undergone some imbalance. This set of conditions caused cells to have short cycle life on regimes 1 and 2. On regime 3, the failure mode was mainly inability of the cell to meet the cycling capacity requirement, which was set at 1.44 Ah output. A cell failing at 60 cycles meant only that its capacity dropped below 1.44 Ah.

CONCLUSION

The program covered the investigation of physical and electrical characteristics of a zinc electrode of novel construction. The fabrication technique involved adding an inorganic refractory type material to the zinc oxide in a small proportion (up to 20%) and sintering the pressed electrode at 850°C, below the melting point of the silver grid of the collector. The sintering had a bonding effect between all the particles, possibly caused by the formation of a solid solution at the particle surface. The resultant electrode had good structural strength, and was capable of handling and of absorbing a small amount of additive (HgO or PbO in the range of 2%) by a wet process.

Physical characteristics were determined for three different inorganic materials added in various ratios ranging from 2% to 50% and sintered at temperatures ranging from 300°C to 1400°C. Selection among the multiple combinations resulted in one inorganic material (Zirconia) added in three different ratios (5, 10, 20%) sintered at one temperature (850°C), the mix being processed in two different ways (sintering the pressed electrode and sintering the mix prior to sintering the pressed electrode).

The electrical tests were carried out on electrodes combining some features of the above selection. The results were compared with those of the standard (unsintered) zinc oxide electrode on three different automatic cycling regimes after establishing their electrical performance on five total discharge cycles run at various rates.

Because of the time and budget limitations of this program, not all electrical data were acquired, but sufficient information was obtained to show a trend and a possible solution to the zinc "slumping" problem. All cells using a sintered ZnO inorganic material mix electrode showed, upon failure analysis, a remarkable zinc shape retention, at least when using a minimum of 10% zirconia in the mix. This fact is associated with the physical integrity of the electrode during fabrication, assembly, cell electrolyte soaking and hence during cycling. These two striking features, structural strength and minimization of shape change during cycling, weigh heavily in favor of such an electrode. It is important to remember that cycle life is not immediately relevant at this time for the following forceful reasons:

This program was designed to quickly screen out and evaluate various zinc electrode constructions (using a sintered mix) on a relative scale on three different test regimes. In order to do this, the test cell was conceived and designed to be zinc limiting for the first cycle, contrary to conventional cell designs where silver is the limiting electrode on charge and discharge and zinc oxide capacity is at least 40 to 60% overdesigned. The test cell was therefore made to reach the full charge of the zinc electrode on every cycle from the very first. This imposes a heavy handicap on the cell from the beginning since this condition promotes zinc penetration and no separator is immune to such severe testing. This explains the relatively short cycle life despite the fact that the zinc electrode still retained good shape, which in a cell of well balanced electrode design with test conditions properly set (no overcharge) would lead to longer cycle life than has been recorded in the previous test cells. It means that a test cell actually starts its cycling under the conditions it would have seen 300 to 500 cycles later, had it been designed in a conventional manner.

In this light, the sintered zinc oxide electrode is a very promising candidate for test in a 5 Ah silver zinc cell of the model tested on another NASA contract* for direct comparison. It is recommended that such a program be considered.

---

*A. Himy, "Development and Testing of a 5 Ah Ag-Zn Cell," Final Report NASA CR-72551, NASA Lewis, NAS 3-10924.

APPENDIX A

PORE SIZE DISTRIBUTION
EXPERIMENTAL DATA CURVES

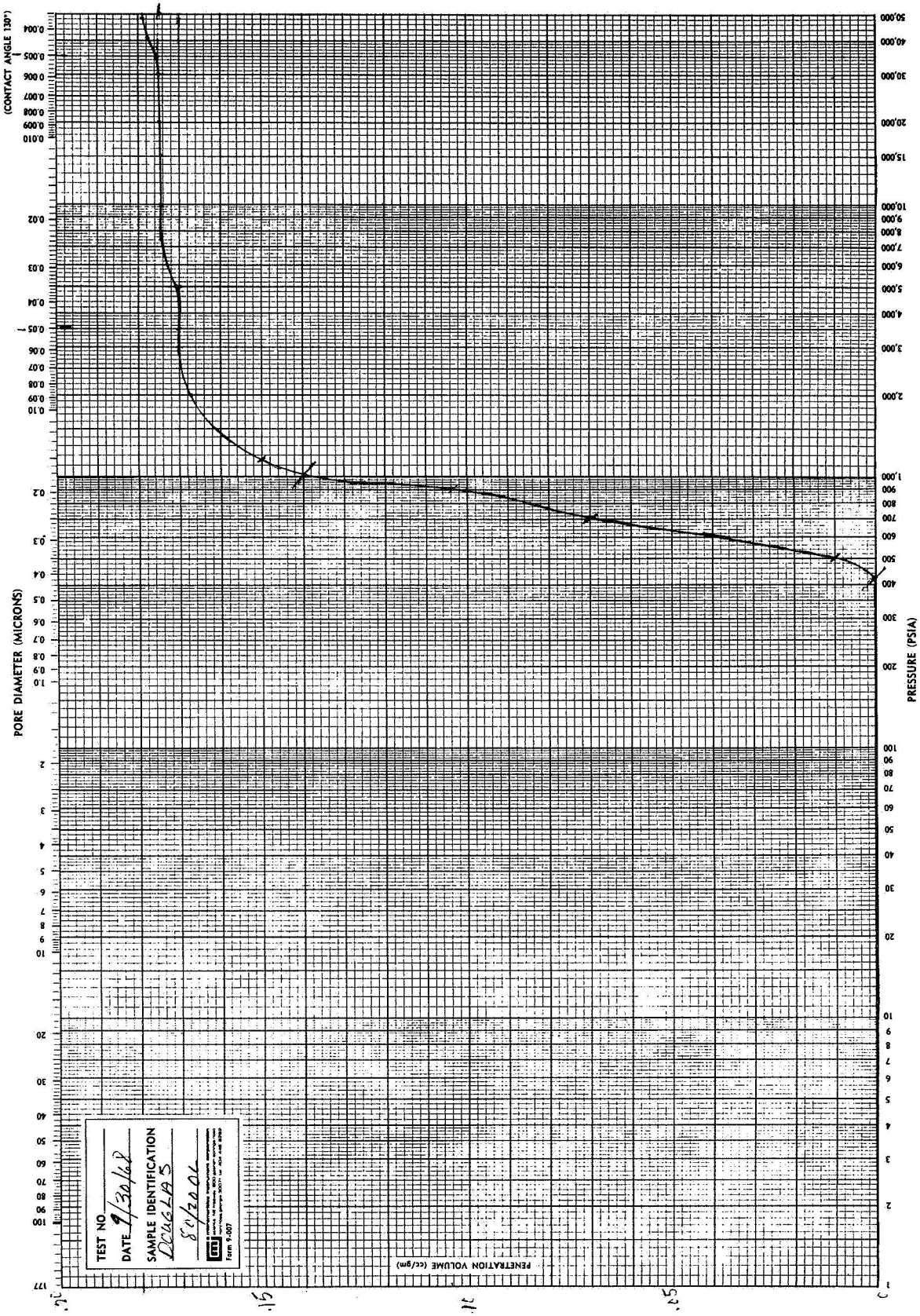


Figure A-1. 80/20 OL

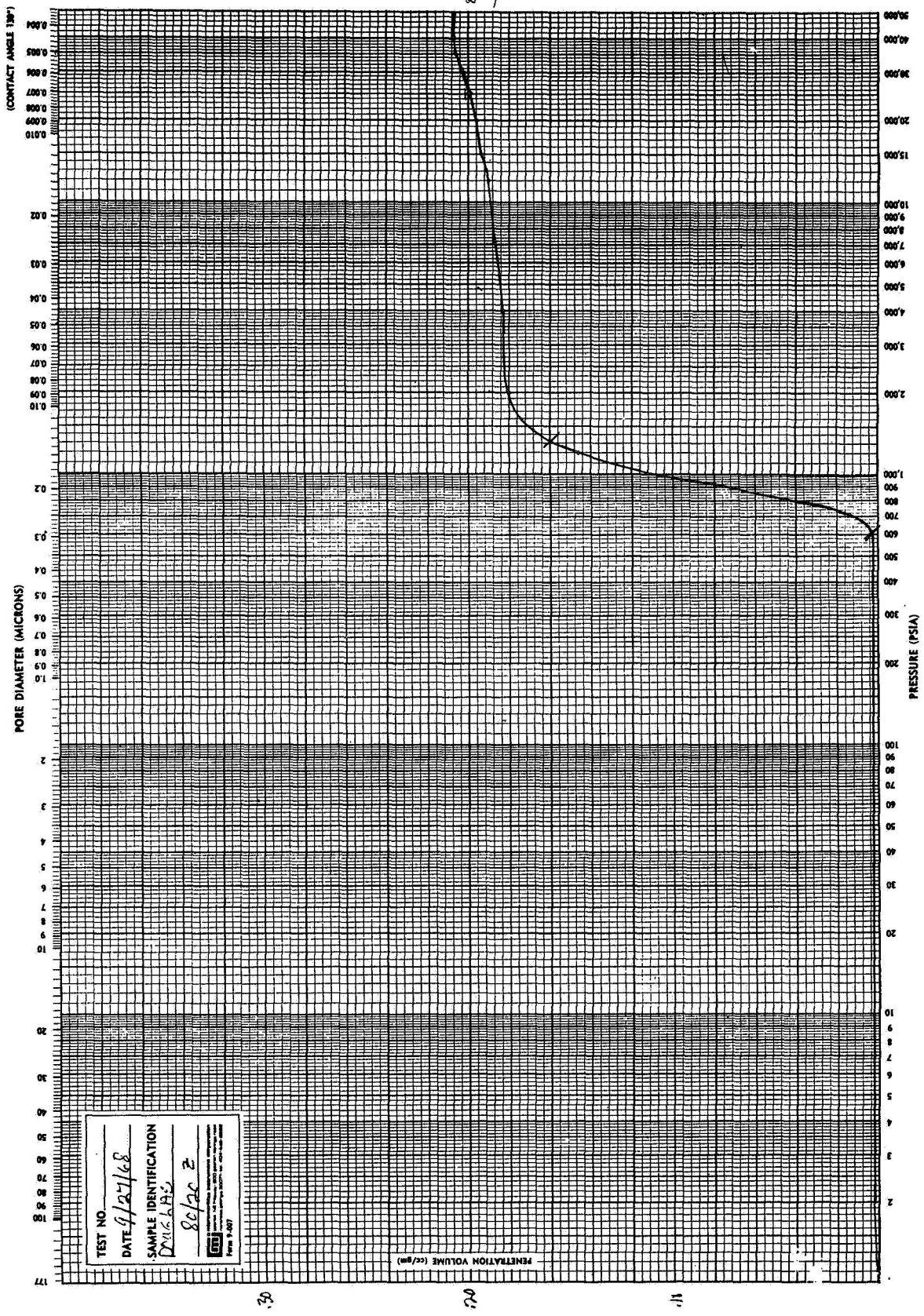


Figure A-2. 80/20 Z

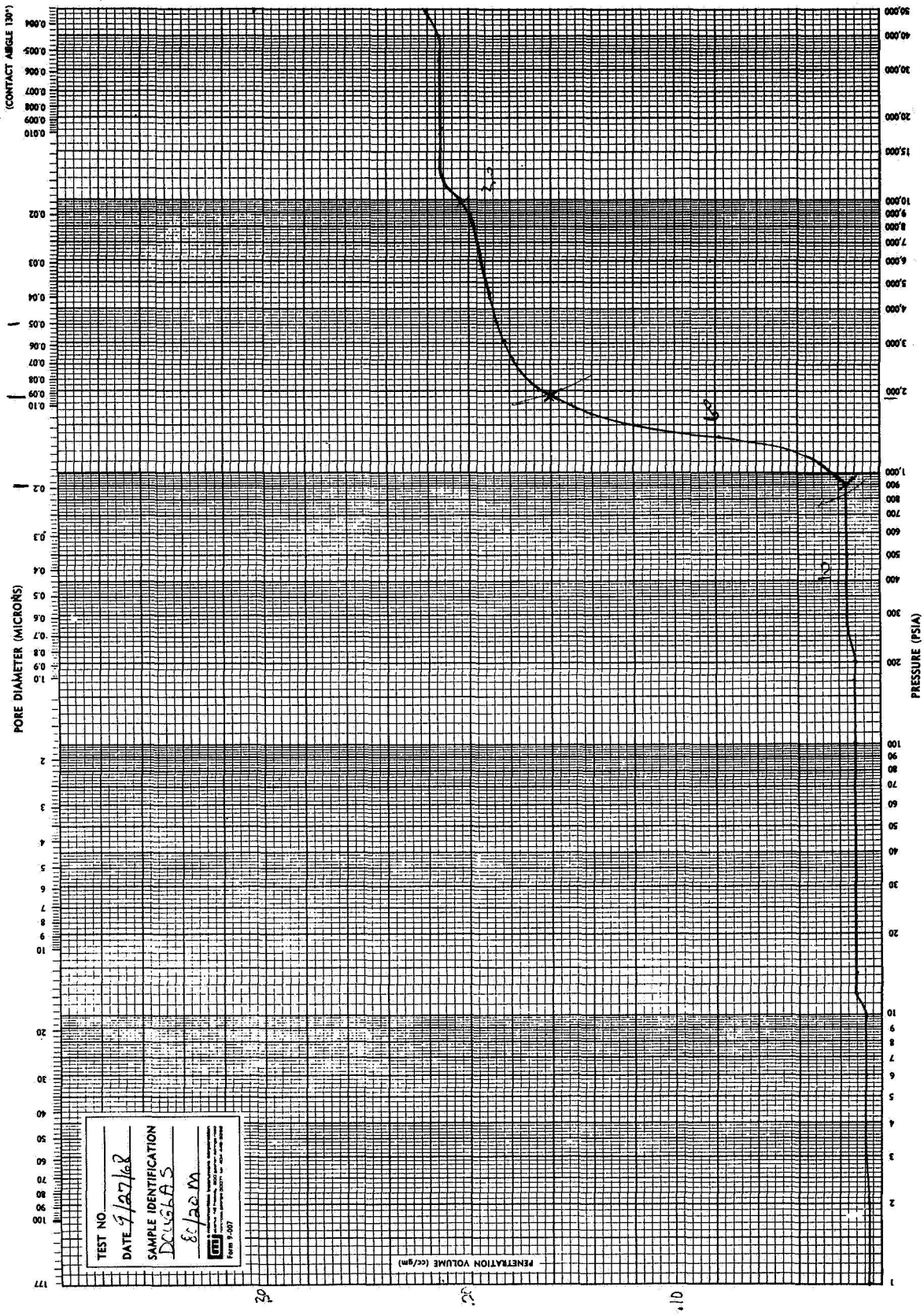


Figure A-3. 80/20 M

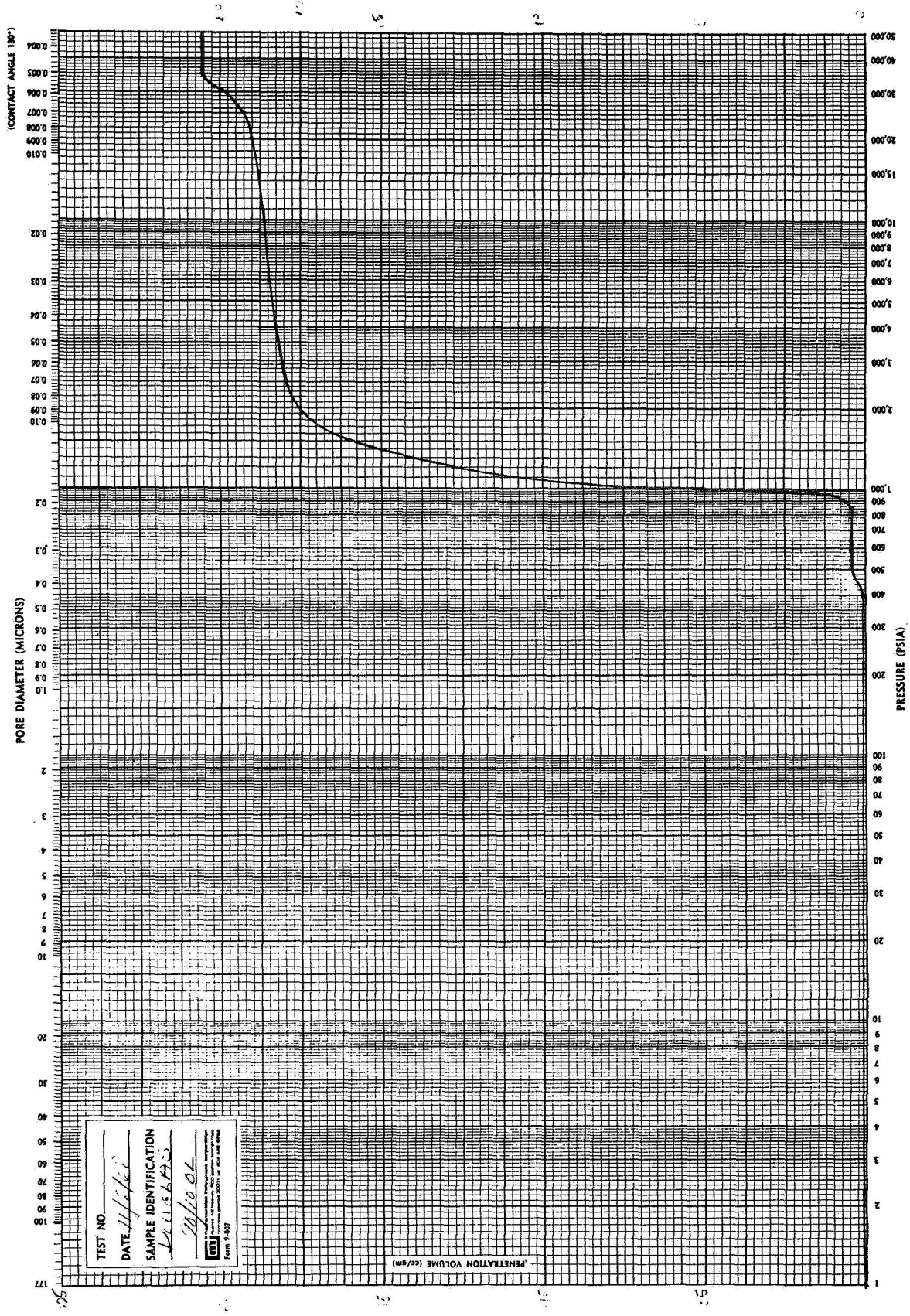


Figure A-4. 90/10 OL (N)

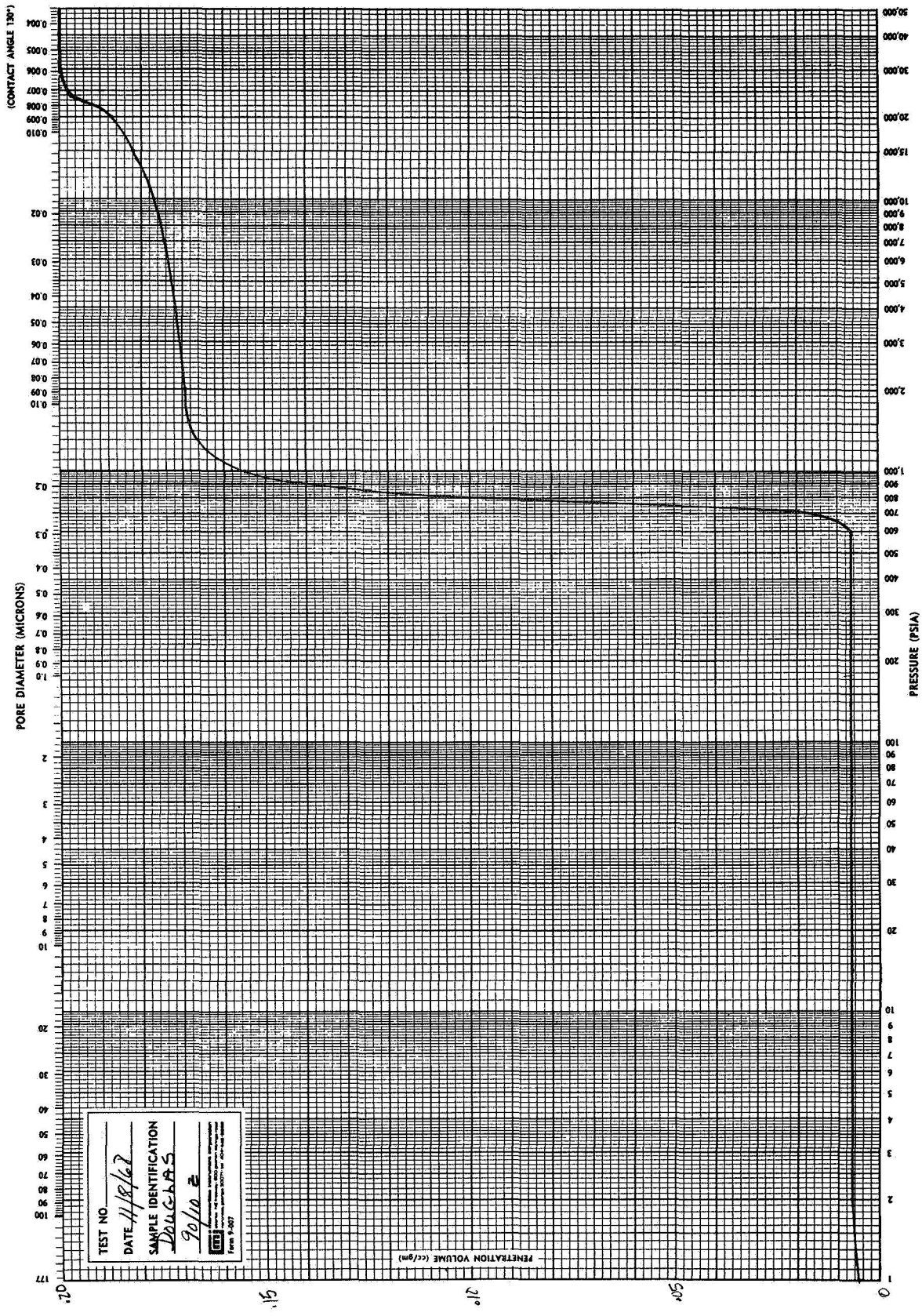


Figure A-5. 90/10 Z (N)

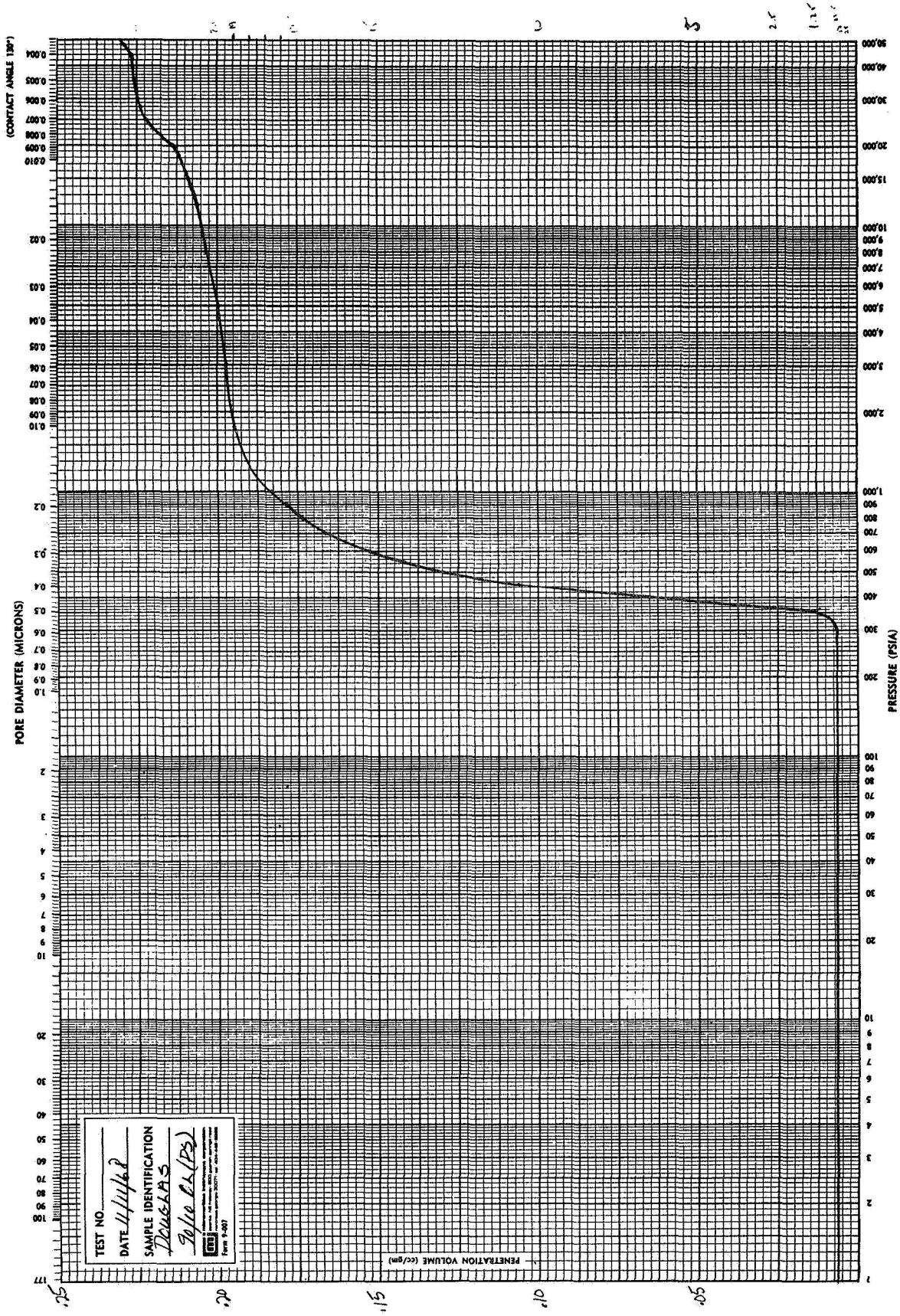


Figure A-6. 90/10 OL (PS)

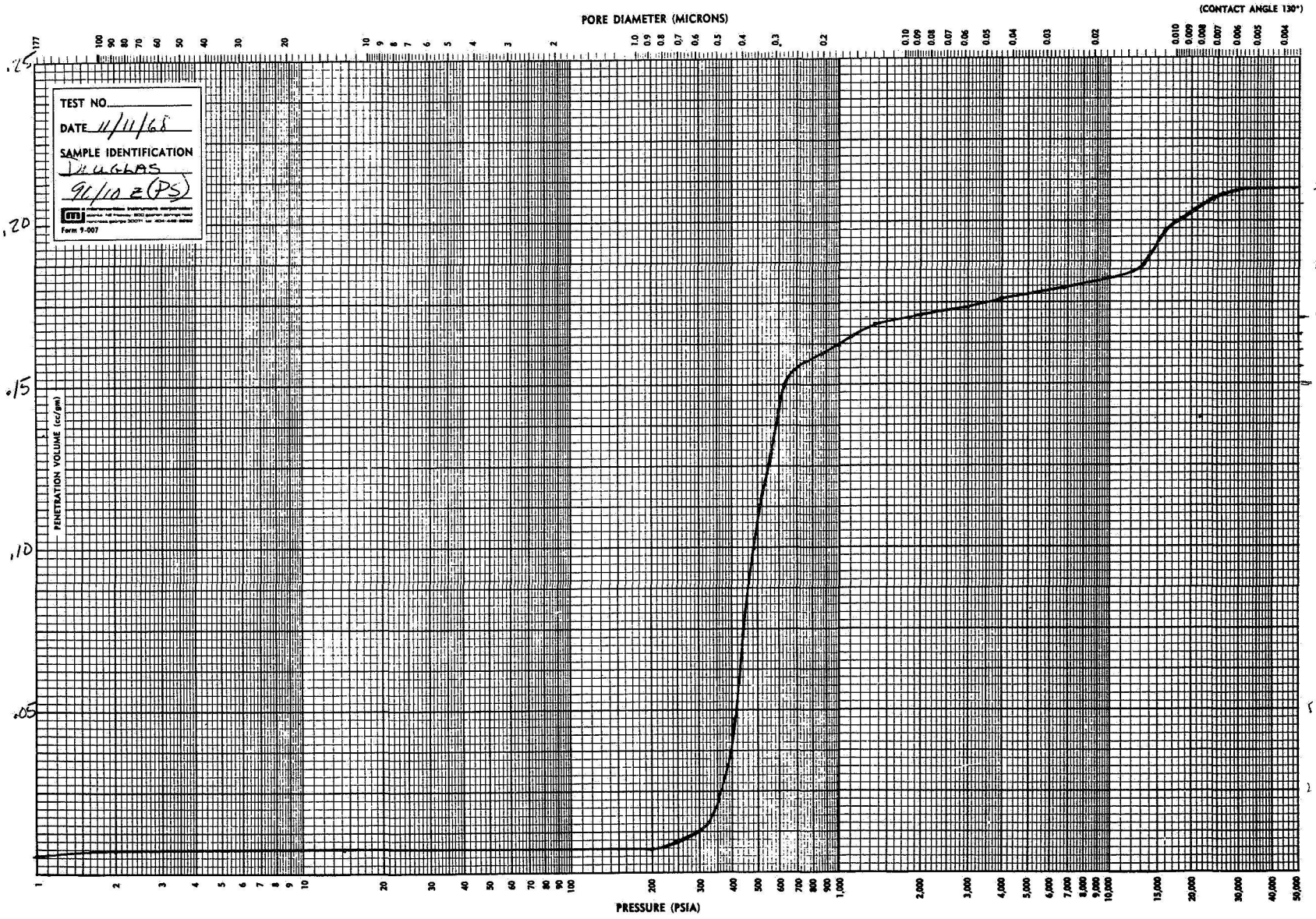
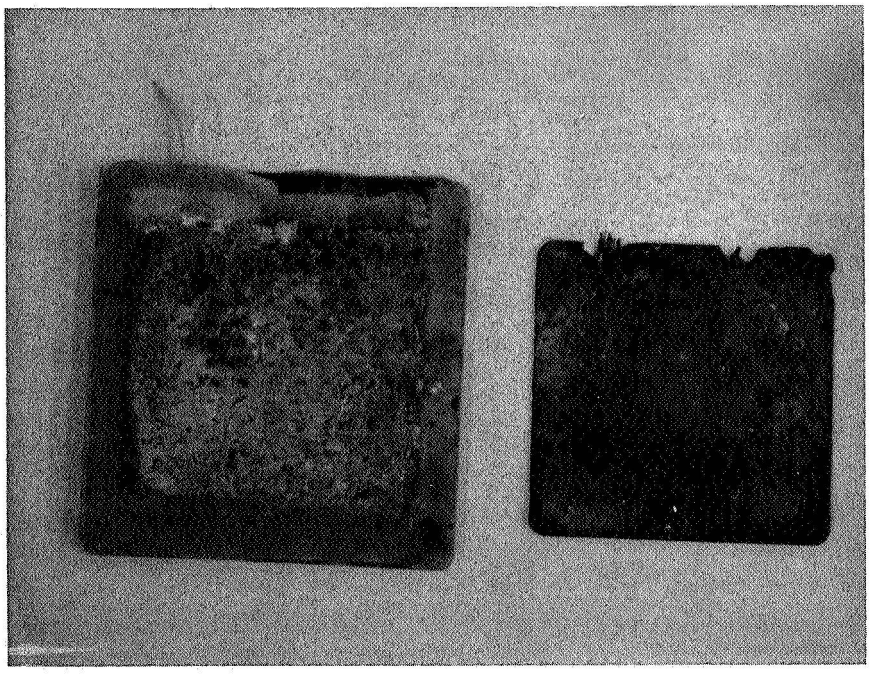


Figure A-7. 90/10 Z (PS)

APPENDIX B

CELL ANALYSES AND ELECTRODE PICTURES



c5709

Figure B-1. Cell Number A-13

CELL ANALYSIS

Cell No. A-13

Regime 1		Combination Control A	
Temperature:	100°C	**Binder:**	None
Period:	1 hr.	**Ratio:**	100/0
Discharge:	0.6 A for 0.5 hr.	**Process:**	Not sintered
Charge:	0.66 A for 0.5 hr.	**Additive (PbO%):**	0
		Grid:	5 Ag 38-1/0
		Design:	(-) W

Original Capacity: Q_o = 2.0 Ah

Last Capacity: Q = 0.2 Ah

Capacity Retention %: $q = \frac{Q}{Q_o} \times 100$ = 10%

Failure Cycle: N = 302

Wet Life: days = 65

Inspection: Separators: No cracks, black stains both sides, no delam., Zn pen. probable failure cause.

Positive active area: p^+ = N. A.

Negative shape retention: p^- = 90%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Gray	Semi-wet
Bottom	Spongy	Gray	Semi-wet

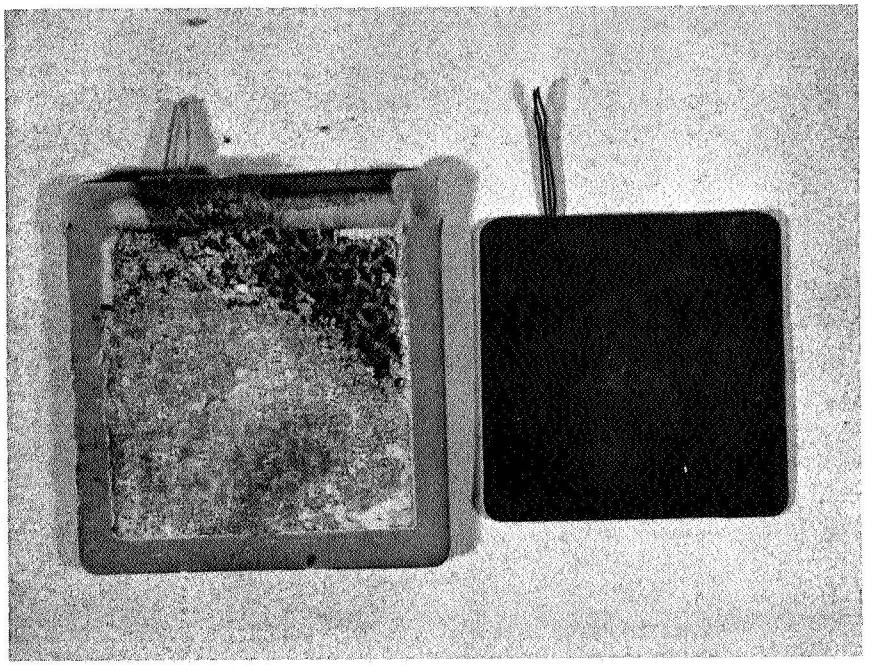
Analysis:

Original ZnO mass: m_o = 5.9 g

Residual ZnO mass: m = 3.6 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 61%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 16%



c5710

Figure B-2. Cell Number A-22

CELL ANALYSIS

Cell No. A-22

Regime 2		Combination Control A	
Temperature:	25°C	Binder:	None
Period:	1.5 hr.	Ratio:	100/0
Discharge:	0.9 A for 0.5 hr.	Process:	Not sintered
Charge:	0.5 A for 1.0 hr.	Additive (PbO%):	0
		Grid:	5 Ag 38-1/0
		Design:	(-) W

Original Capacity: Q_o = 2.0 Ah

Last Capacity: Q = 0.4 Ah

Capacity Retention %: $q = \frac{Q}{Q_o} \times 100 =$ 20%

Failure Cycle: N = 502

Wet Life: days = 96

Inspection:

Separators: No cracks, no delam., few dark stains, Zn pen. signs.

Positive active area: p^+ = N. A.

Negative shape retention: p^- = 80%

Zinc electrode condition: Fair

Plate Location	Density	Color	Wetness
Top	Spongy	Gray	Semi-wet
Bottom	Spongy	Gray	Semi-wet

Analysis:

Original ZnO mass: m_o = 5.9 g

Residual ZnO mass: m = 4.5 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100 =$ 76%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100 =$ 26%

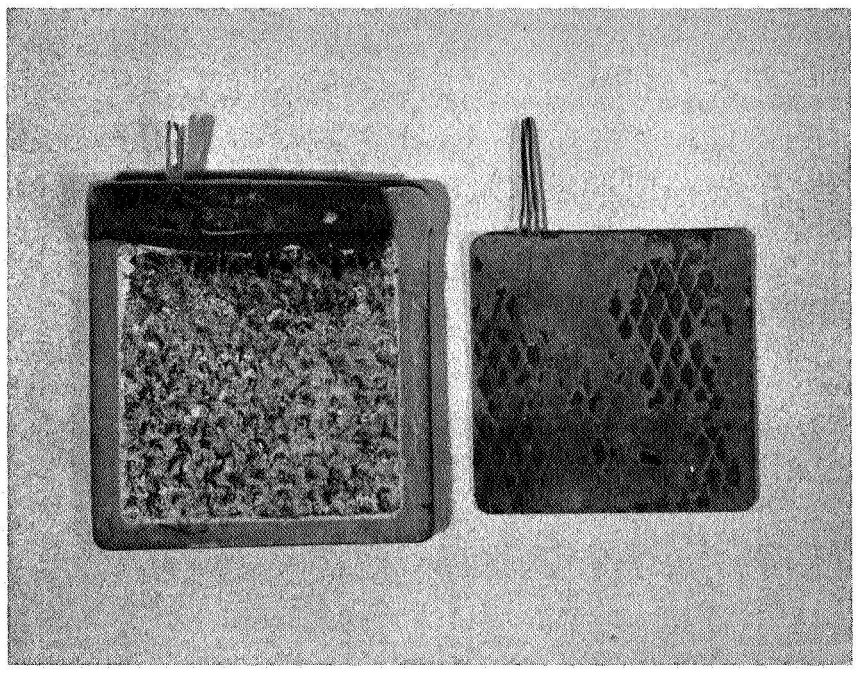


Figure B-3. Cell Number A-32

CELL ANALYSIS

Cell No. A-32

Regime 3		Combination Control A	
Temperature:	25°C	Binder:	None
Period:	24 hr.	Ratio:	100/0
Discharge:	1.2 A for 1.2 hr.	Process:	Not sintered
Charge:	0.07 A for 22.8 hr.	Additive (PbO%):	0
		Grid:	5 Ag 38-1/0
		Design:	(-) W

Original Capacity: Q_o = 2.0 Ah

Last Capacity: Q = 1.2 Ah

Capacity Retention %: $q = \frac{Q}{Q_o} \times 100 = 60\%$

Failure Cycle: N = 60

Wet Life: days = 107

Inspection:

Separators: No cracks or delam., few dark stains, signs of Zn pen.

Positive active area: p^+ = 100%

Negative shape retention: p^- = 80%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Gray	Wet
Bottom	Spongy	Gray	Wet

Analysis:

Original ZnO mass: m_o = 5.9 g

Residual ZnO mass: m = 4.8 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100 =$ 81%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100 =$ 74%

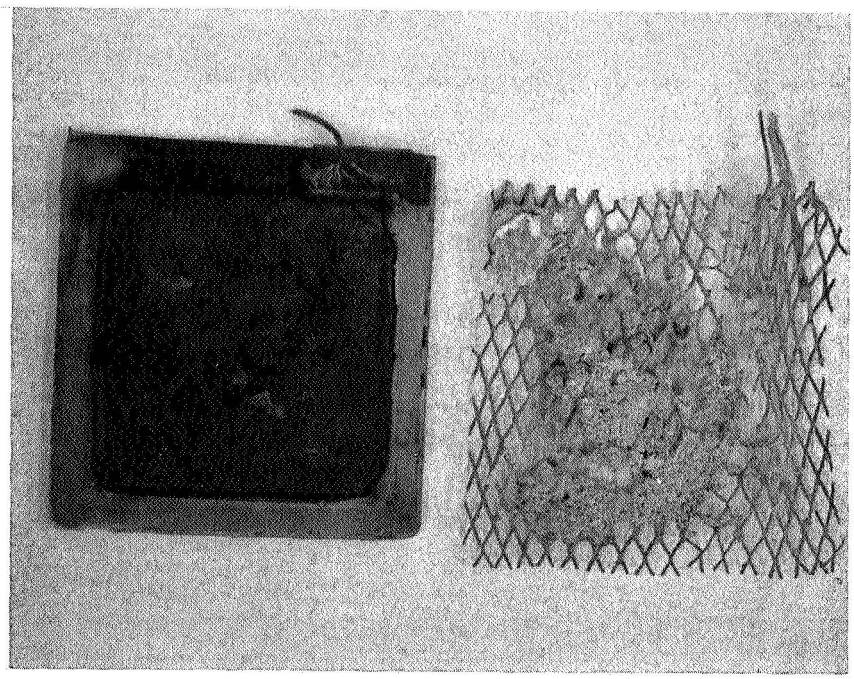


Figure B-4. Cell Number 112A

CELL ANALYSIS

Cell No. 112A

Regime 1		Combination 1	
Temperature:	100°C	Binder:	Z
Period:	1 hr.	Ratio:	90/10
Discharge:	0.6 A for 0.5 hr.	Process:	N
Charge:	0.66 A for 0.5 hr.	Additive (PbO%):	0
		Grid:	5 Ag 14-1/0
		Design:	(+) W

Original Capacity:	Q_o =	2.0 Ah
Last Capacity:	Q =	0.1 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	5%
Failure Cycle:	N =	500
Wet Life:	days =	90

Inspection:

Separators: No cracks or delam., dark stains on Ag side, signs of Zn pen.

Positive active area: p^+ = N.A.

Negative shape retention: p^- = 50%

Zinc electrode condition: Fair

Plate Location	Density	Color	Wetness
Top	Loose	Gray	Wet
Bottom	Loose	Gray	Wet

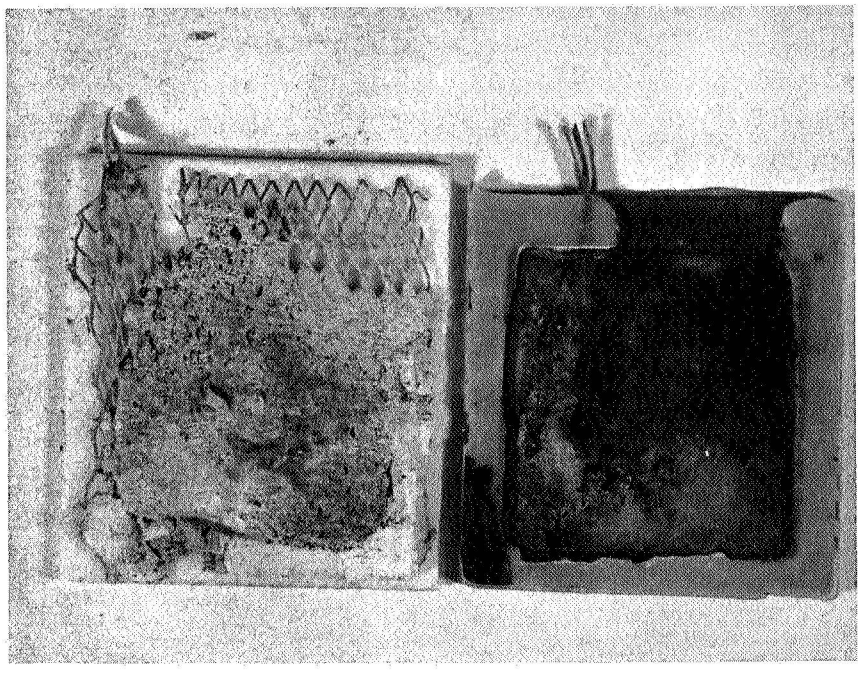
Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 2.0 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 37%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 14%



c5713

Figure B-5. Cell Number 123A

CELL ANALYSIS

Cell No. 123A

Regime 2		Combination 1	
Temperature:	25°C	Binder:	Z
Period:	1.5 hr	Ratio:	90/10
Discharge:	0.9 A for 0.5 hr.	Process:	N
Charge:	0.5 A for 1.0 hr.	Additive (PbO%):	0
		Grid:	5 Ag 14-1/0
		Design:	(+) W

Original Capacity:	Q_o =	2.0 Ah
Last Capacity:	Q =	0.4 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	20%
Failure Cycle:	N =	591
Wet Life:	days =	114

Inspection:

Separators: No cracks, no delam., some dark stains, signs of Zn pen.

Positive active area: p^+ = N.A.

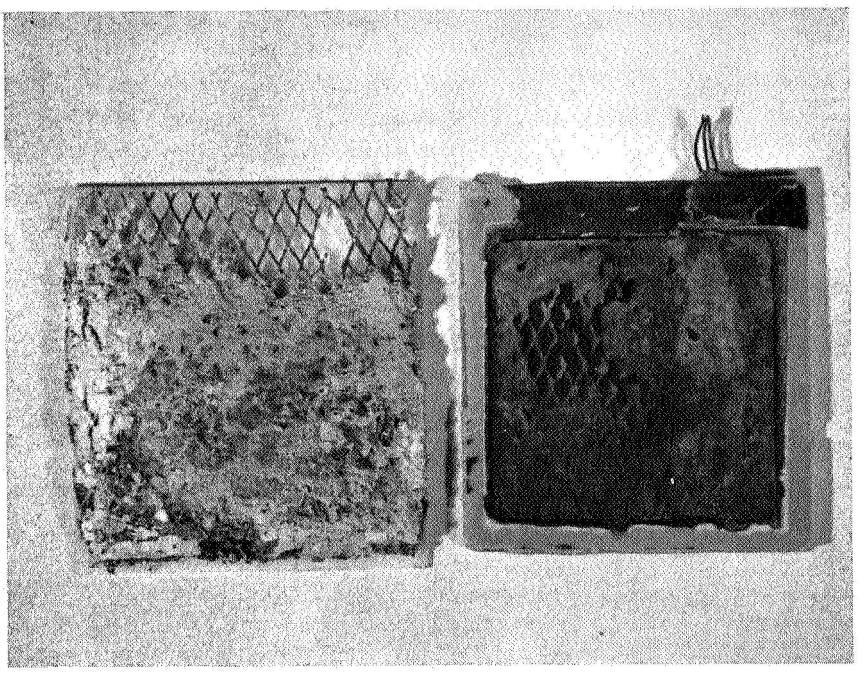
Negative shape retention: p^- = 75%

Zinc electrode condition: Fair

Plate Location	Density	Color	Wetness
Top	Loose	Gray	Wet
Bottom	Loose	Gray	Wet

Analysis:

Original ZnO mass: m_o =	5.4 g
Residual ZnO mass: m =	3.7 g
ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ =	69%
Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ =	29%



C5714

Figure B-6. Cell Number 131

CELL ANALYSIS

Cell No. 131

Regime 3		Combination 1	
Temperature:	25°C	Binder:	Z
Period:	24 hr.	Ratio:	90/10
Discharge:	1.2 A for 1.2 hr.	Process:	N
Charge:	0.07 A for 22.8 hr.	Additive (PbO%):	0
		Grid:	5 Ag 14-1/0
		Design:	(+) W

Original Capacity:	Q_o =	2.3 Ah
Last Capacity:	Q =	1.4 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	61%
Failure Cycle:	N =	118
Wet Life:	days =	184

Inspection: Separators: No cracks or delam., Zn pen signs, some Zn on far side of Ag wafer.

Positive active area: p^+ = 100%

Negative shape retention: p^- = 90%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Gray	Wet
Bottom	Spongy	Gray	Wet

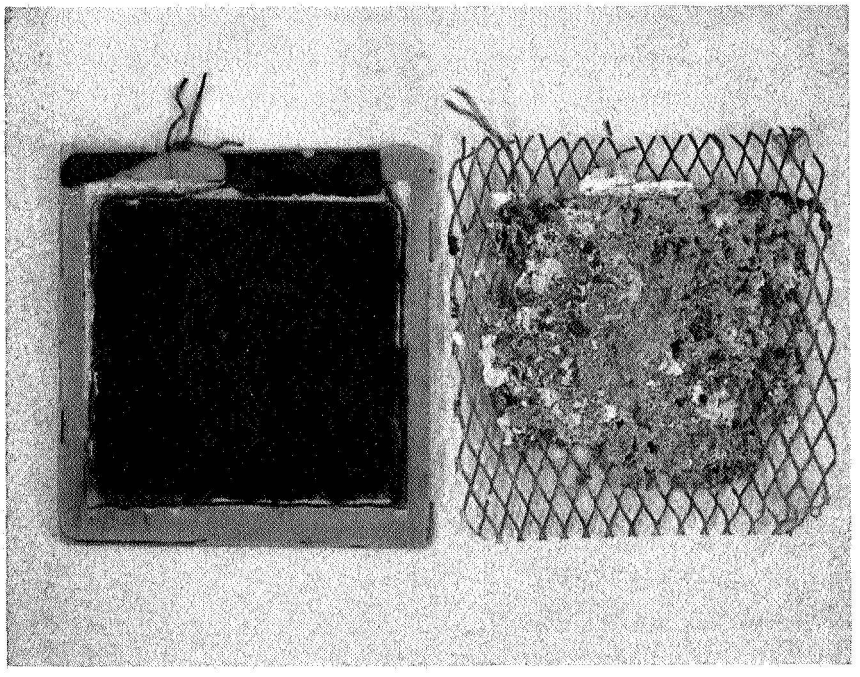
Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 3.5 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 65%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 94%



C5715

Figure B-7. Cell Number 132

CELL ANALYSIS

Cell No. 132

Regime 3		Combination 1	
Temperature:	25°C	Binder:	Z
Period:	24 hr.	Ratio:	90/10
Discharge:	1.2 A for 1.2 hr.	Process:	N
Charge:	0.07 A for 22.8 hr.	Additive (PbO%):	0
		Grid:	5 Ag 14-1/0
		Design:	(+) W

Original Capacity:	Q_o =	2.3 Ah
Last Capacity:	Q =	1.4 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	61%
Failure Cycle:	N =	46
Wet Life:	days =	90

Inspection:

Separators: No cracks or delam., some dark stains, Zn pen. still gassing.

Positive active area: p^+ = N.A.

Negative shape retention: p^- = 90%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Gray	Wet
Bottom	Spongy	Gray	Wet

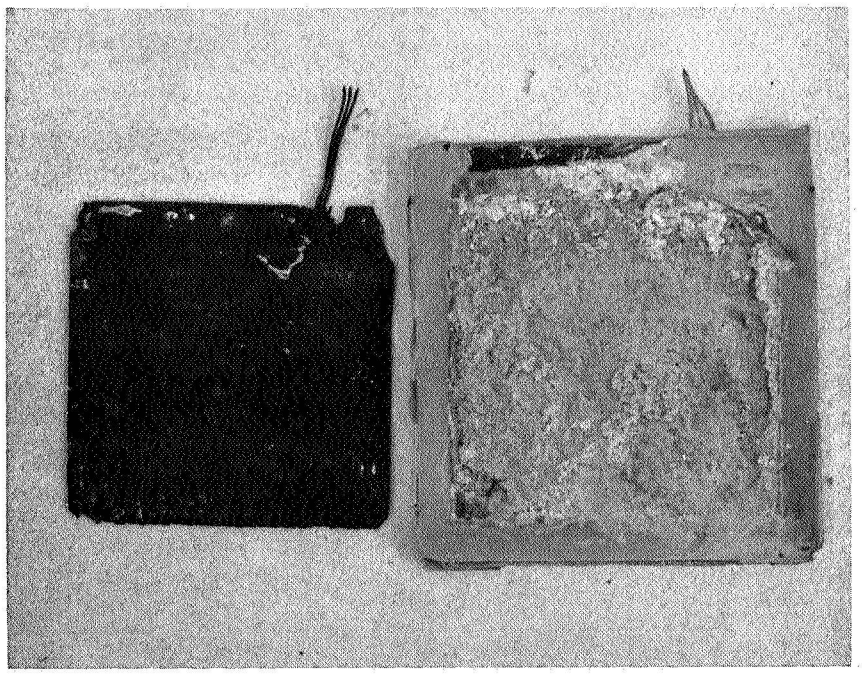
Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 3.7 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 69%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 88%



C5716

Figure B-8. Cell Number 212A

CELL ANALYSIS

Cell No. 212A

Regime 1		Combination 2	
Temperature:	100°C	Binder:	Z
Period:	1 hr.	Ratio:	90/10
Discharge:	0.6 A for 0.5 hr.	Process:	N
Charge:	0.66 A for 0.5 hr.	Additive (PbO%):	0
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.1 Ah
Last Capacity:	Q =	0.2 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	10%
Failure Cycle:	N =	299
Wet Life:	days =	60

Inspection: Separators: One cracked separator, no delam., dark stains, Zn pen. still gassing.

Positive active area: p^+ = N. A.

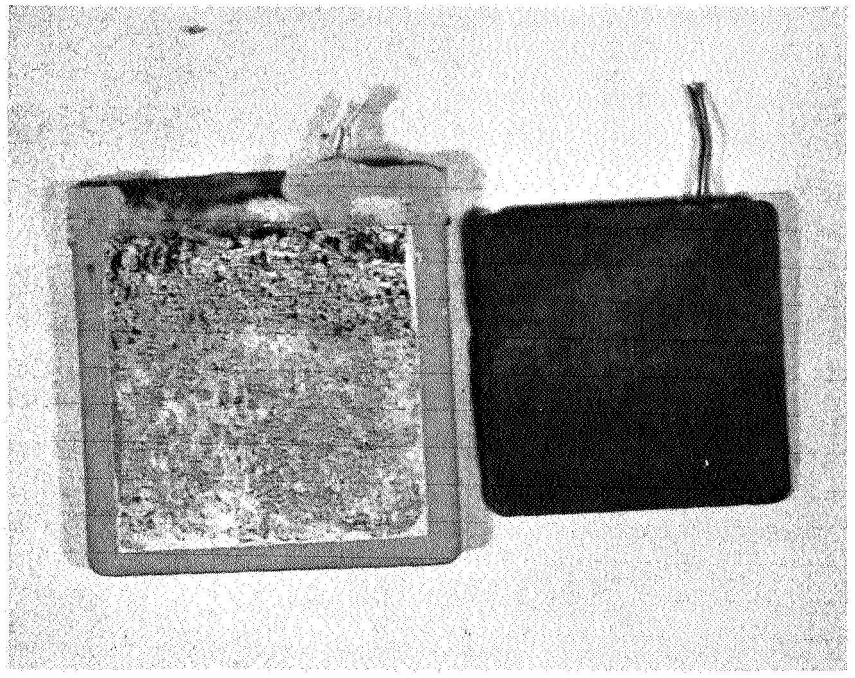
Negative shape retention: p^- = 100%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Blue-Gray	Semi-wet
Bottom	Spongy	Blue-Gray	Semi-wet

Analysis:

Original ZnO mass:	m_o =	5.4 g
Residual ZnO mass:	m =	3.4 g
ZnO retention %:	$\zeta = \frac{m}{m_o} \times 100$ =	63%
Final-to-original utilization ratio (%):	$\eta = \frac{q}{\zeta} \times 100$ =	16%



c5717

Figure B-9. Cell Number 223A

CELL ANALYSIS

Cell No. 223A

Regime 2		Combination 2	
Temperature:	25°C	Binder:	Z
Period:	1.5 hr.	Ratio:	90/10
Discharge:	0.9 A for 0.5 hr.	Process:	N
Charge:	0.5 A for 1.0 hr.	Additive (PbO%):	0
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.0 Ah
Last Capacity:	Q =	0.5 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	25%
Failure Cycle:	N =	500
Wet Life:	days =	86

Inspection:

Separators: No cracks or delam., few dark stains, signs of Zn pen.

Positive active area: p^+ = N.A.

Negative shape retention: p^- = 80%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Gray	Semi-wet
Bottom	Spongy	Gray	Semi-wet

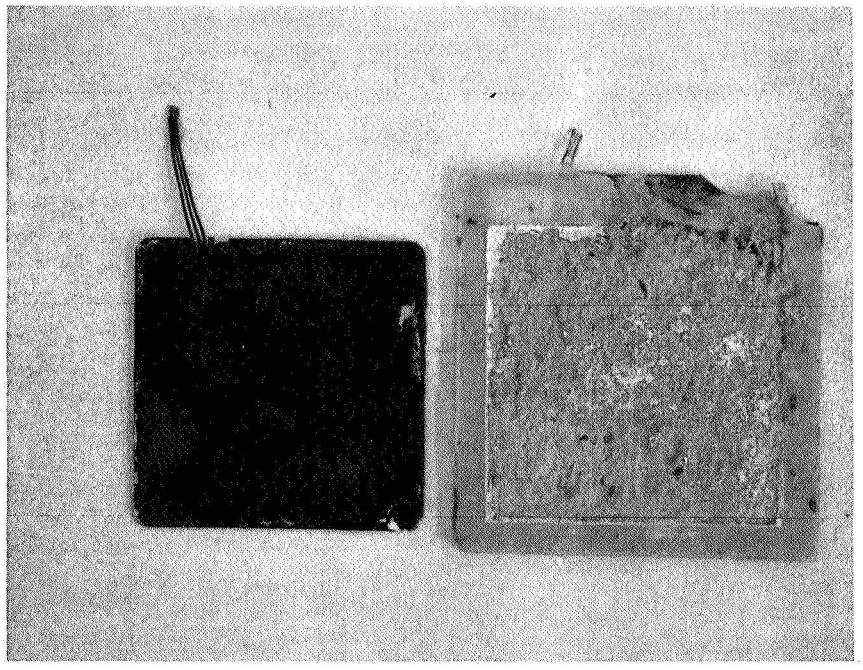
Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 3.9 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 72%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 35%



C5718

Figure B-10. Cell Number 232

CELL ANALYSIS

Cell No. 232

Regime 3		Combination 2	
Temperature:	25°C	Binder:	Z
Period:	24 hr.	Ratio:	90/10
Discharge:	1.2 A for 1.2 hr.	Process:	N
Charge:	0.07 A for 22.8 hr.	Additive (PbO%):	0
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.3 Ah
Last Capacity:	Q =	1.5 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	65%
Failure Cycle:	N =	63
Wet Life:	days =	111

Inspection: Separators: No cracks or delam., dark stains, some Zn pen., still gassing.

Positive active area: p^+ = N.A.

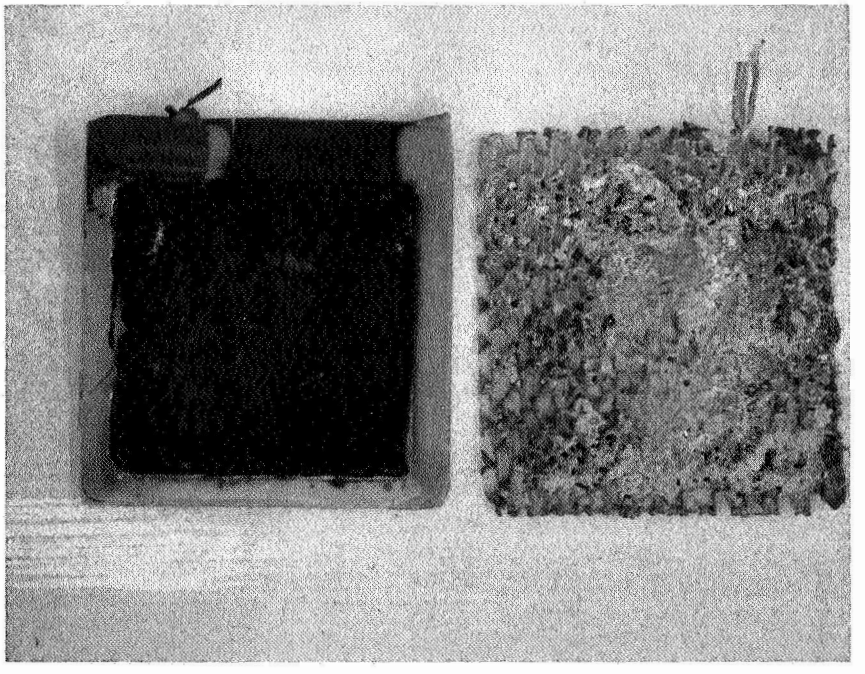
Negative shape retention: p^- = 100%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Loose	Blue-Gray	Semi-wet
Bottom	Spongy	Blue-Gray	Semi-wet

Analysis:

Original ZnO mass: m_o =	5.4 g
Residual ZnO mass: m =	3.9 g
ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ =	72%
Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ =	90%



c5719

Figure B-11. Cell Number 313A

CELL ANALYSIS

Cell No. 313A

Regime 1		Combination 3	
Temperature:	100°C	Binder:	Z
Period:	1 hr.	Ratio:	90/10
Discharge:	0.6 A for 0.5 hr.	Process:	N
Charge:	0.66 A for 0.5 hr.	Additive (PbO%):	0
		Grid:	5 Ag 38-1/0
		Design:	(+) W

Original Capacity:	Q_o =	2.1 Ah
Last Capacity:	Q =	0.2 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	10%
Failure Cycle:	N =	299
Wet Life:	days =	60

Inspection: Separators: No cracks or delam., some dark stains, Zn pen., still gassing.

Positive active area: p^+ = N.A.

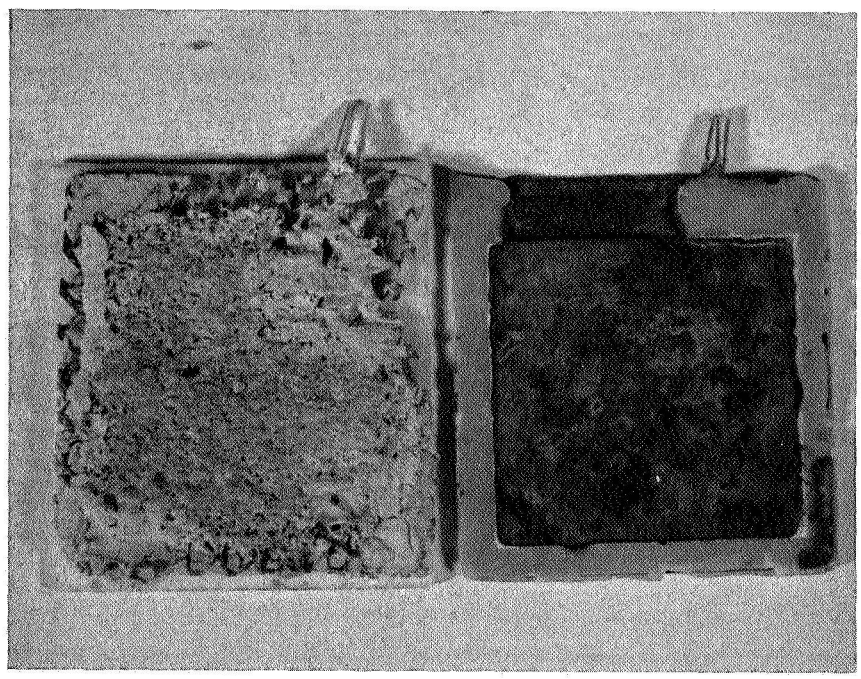
Negative shape retention: p^- = 50%

Zinc electrode condition: Fair

Plate Location	Density	Color	Wetness
Top	Loose	Gray	Semi-wet
Bottom	Loose	Gray	Semi-wet

Analysis:

Original ZnO mass: m_o =	5.4 g
Residual ZnO mass: m =	2.5 g
ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ =	46%
Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ =	22%



C5720

Figure B-12. Cell Number 322A

CELL ANALYSIS

Cell No. 322A

Regime 2		Combination 3	
Temperature:	25°C	Binder:	Z
Period:	1.5 hr.	Ratio:	90/10
Discharge:	0.9 A for 0.5 hr.	Process:	N
Charge:	0.5 A for 1.0 hr.	Additive (PbO%):	0
		Grid:	5 Ag 38-1/0
		Design:	(+) W

Original Capacity:	Q_o =	2.1 Ah
Last Capacity:	Q =	0.4 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	19%
Failure Cycle:	N =	593
Wet Life:	days =	114

Inspection:

Separators: No cracks or delam., signs of Zn pen.

Positive active area: p^+ = N.A.

Negative shape retention: p^- = 100%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Gray	Wet
Bottom	Spongy	Gray	Wet

Analysis:

Original ZnO mass: m_o =	5.4 g
Residual ZnO mass: m =	3.9 g
ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ =	72%
Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ =	26%

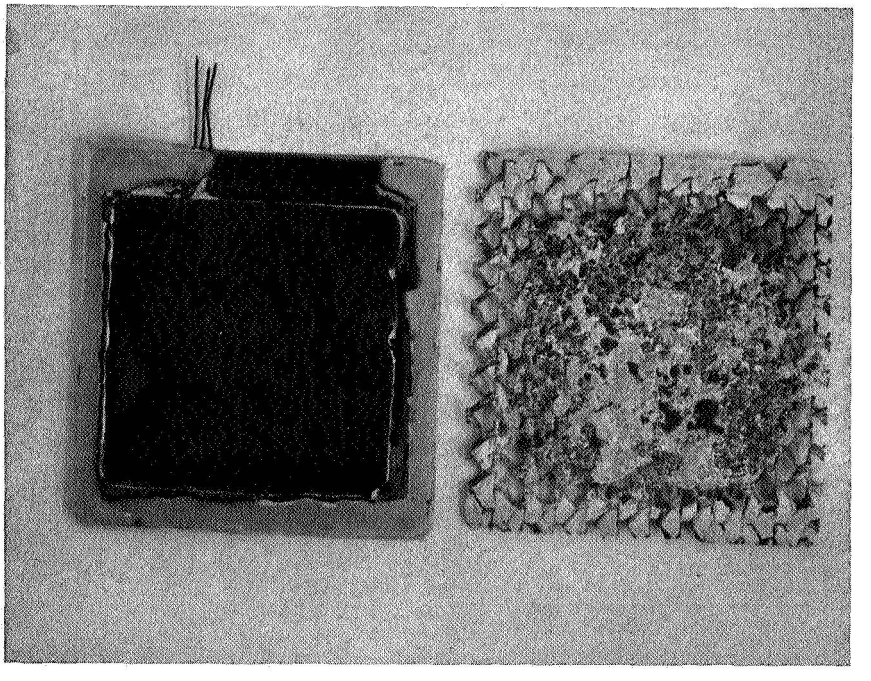


Figure B-13. Cell Number 332

CELL ANALYSIS

Cell No. 332

Regime 3		Combination 3	
Temperature:	25°C	Binder:	Z
Period:	24 hr.	Ratio:	90/10
Discharge:	1.2 A for 1.2 hr.	Process:	N
Charge:	0.07 A for 22.8 hr.	Additive (PbO%):	0
		Grid:	5 Ag 38-1/0
		Design:	(+) W

Original Capacity:	Q_o =	2.3 Ah
Last Capacity:	Q =	1.4 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	61%
Failure Cycle:	N =	36
Wet Life:	days =	111

Inspection: Separators: No cracks or delam., dark stains and Zn pen., still gassing.

Positive active area: p^+ = N. A.

Negative shape retention: p^- = 90%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Blue-Gray	Semi-wet
Bottom	Spongy	Blue-Gray	Semi-wet

Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 3.9 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 72%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 85%

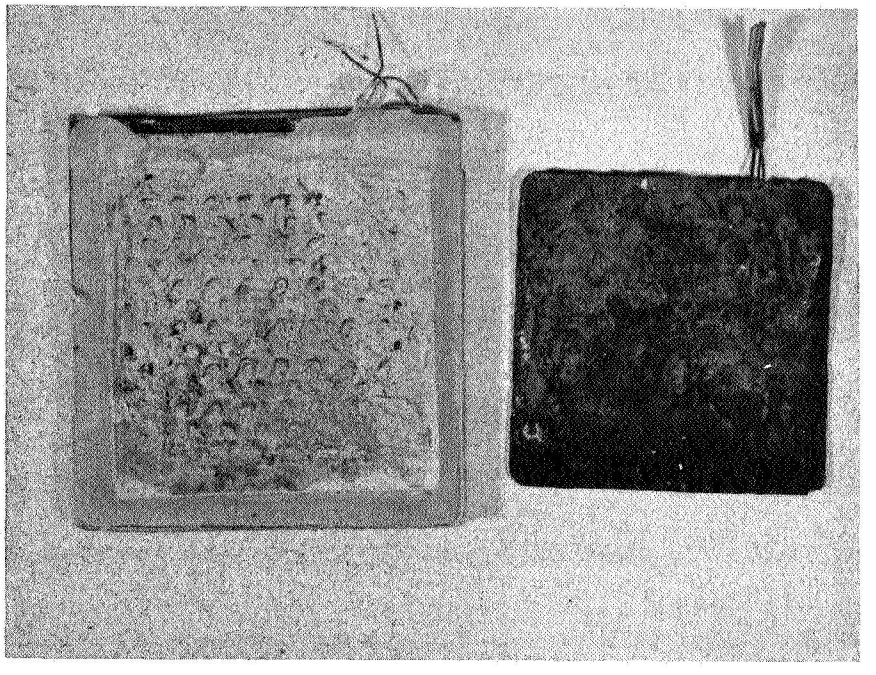


Figure B-14. Cell Number 412A

CELL ANALYSIS

Cell No. 412A

Regime 1		Combination 4	
Temperature:	100°C	Binder:	Z
Period:	1 hr.	Ratio:	90/10
Discharge:	0.6 A for 0.5 hr.	Process:	N
Charge:	0.66 A for 0.5 hr.	Additive (PbO%):	0
		Grid:	5 Ag 38-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.1 Ah
Last Capacity:	Q =	0.1 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	5%
Failure Cycle:	N =	299
Wet Life:	days =	57

Inspection: Separators: No cracks or delam., dark stains and some Zn pen.

Positive active area: p^+ = N.A.

Negative shape retention: p^- = 90%

Zinc electrode condition: Fair

Plate Location	Density	Color	Wetness
Top	Loose	Gray	Wet
Bottom	Spongy	Gray	Wet

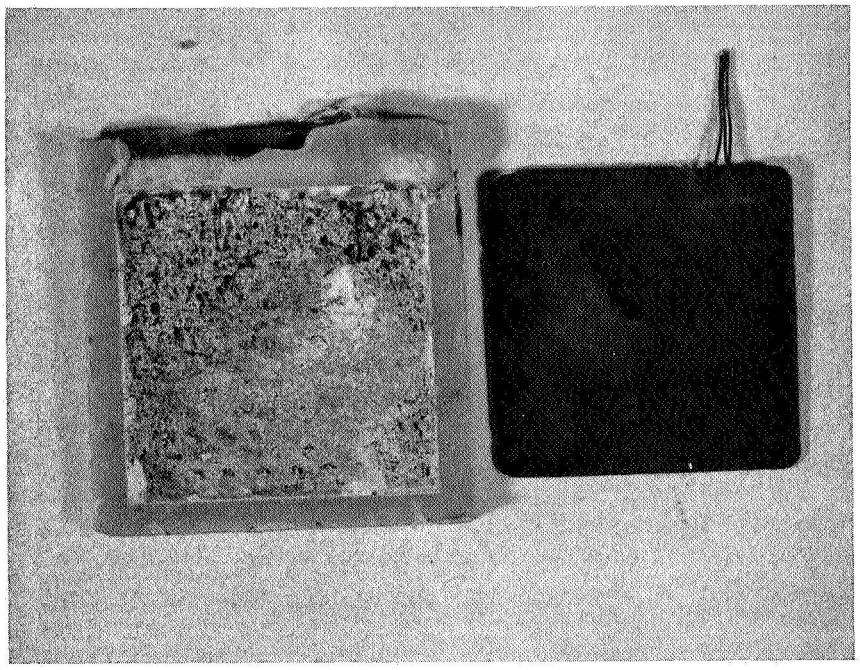
Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 2.7 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 50%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 10%



CS723

Figure B-15. Cell Number 421A

CELL ANALYSIS

Cell No. 421A

Regime 2		Combination 4	
Temperature:	25°C	Binder:	Z
Period:	1.5 hr.	Ratio:	90/10
Discharge:	0.9 A for 0.5 hr.	Process:	N
Charge:	0.5 A for 1.0 hr.	Additive (PbO%):	0
		Grid:	5 Ag 38-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.2 Ah
Last Capacity:	Q =	0.4 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	18%
Failure Cycle:	N =	581
Wet Life:	days =	114

Inspection:

Separators: No cracks or delam., few stains, signs of Zn pen.

Positive active area: p^+ = N.A.

Negative shape retention: p^- = 80%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Loose	Gray	Semi-wet
Bottom	Spongy	Gray	Semi-wet

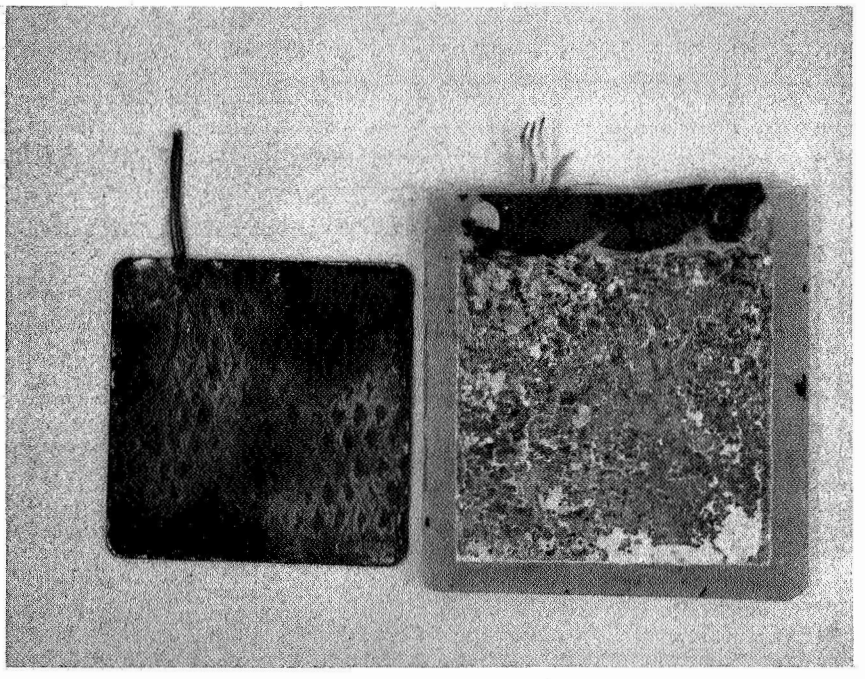
Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 4.0 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 74%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 24%



C5724

Figure B-16. Cell Number 431

CELL ANALYSIS

Cell No. 431

Regime 3		Combination 4	
Temperature:	25°C	Binder:	Z
Period:	24 hr.	Ratio:	90/10
Discharge:	1.2 A for 1.2 hr.	Process:	N
Charge:	0.07 A for 22.8 hr.	Additive (PbO%):	0
		Grid:	5 Ag 38-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.3 Ah
Last Capacity:	Q =	1.5 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	65%
Failure Cycle:	N =	52
Wet Life:	days =	90

Inspection: Separators: No cracks or delam., dark blotchy stains, Zn pen. still gassing.

Positive active area: p^+ = N. A.

Negative shape retention: p^- = 100%

Zinc electrode condition: Excellent

Plate Location	Density	Color	Wetness
Top	Hard	Gray	Semi-wet
Bottom	Hard	Gray	Semi-wet

Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 4.0 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 74%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 88%

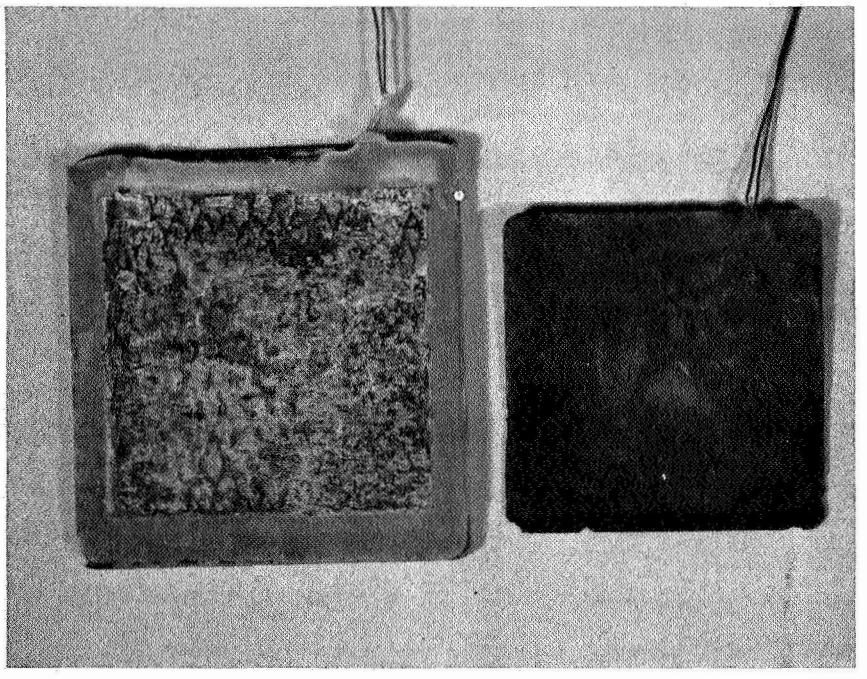


Figure B-17. Cell Number 1311

CELL ANALYSIS

Cell No. 1311

Regime 1		Combination 13	
Temperature:	100°C	Binder:	Z
Period:	1 hr.	Ratio:	90/10
Discharge:	0.6 A for 0.5 hr.	Process:	N
Charge:	0.66 A for 0.5 hr.	Additive (PbO%):	1
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.0 Ah
Last Capacity:	Q =	0.6 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	33%
Failure Cycle:	N =	373
Wet Life:	days =	53

Inspection: Separators: One cracked, no delam., dark stains, signs of Zn pen.

Positive active area: p^+ = 100%

Negative shape retention: p^- = 90%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Blue-Gray	Semi-wet
Bottom	Spongy	Blue-Gray	Semi-wet

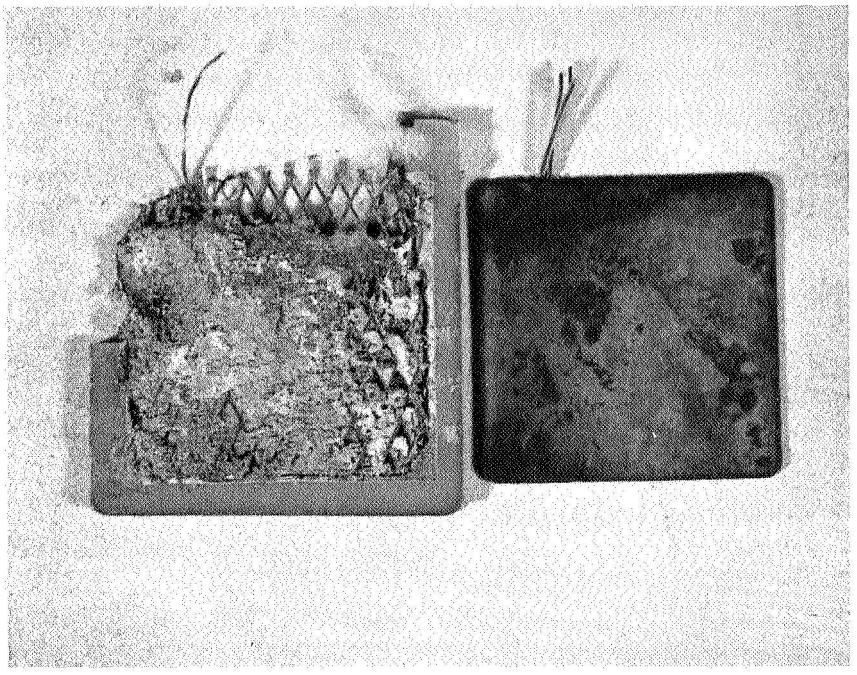
Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 3.2 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 59%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 56%



65726

Figure B-18. Cell Number 1321

CELL ANALYSIS

Cell No. 1321

Regime 2		Combination 13	
Temperature:	25°C	Binder:	Z
Period:	1.5 hr.	Ratio:	90/10
Discharge:	0.9 A for 0.5 hr.	Process:	N
Charge:	0.5 A for 1.0 hr.	Additive (PbO%):	1
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.1 Ah
Last Capacity:	Q =	0.4 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	19%
Failure Cycle:	N =	203
Wet Life:	days =	41

Inspection:

Separators: No cracks or delam., few stains, signs of Zn pen.

Positive active area: p^+ = N.A.

Negative shape retention: p^- = 80%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Gray	Semi-wet
Bottom	Hard	Gray	Semi-wet

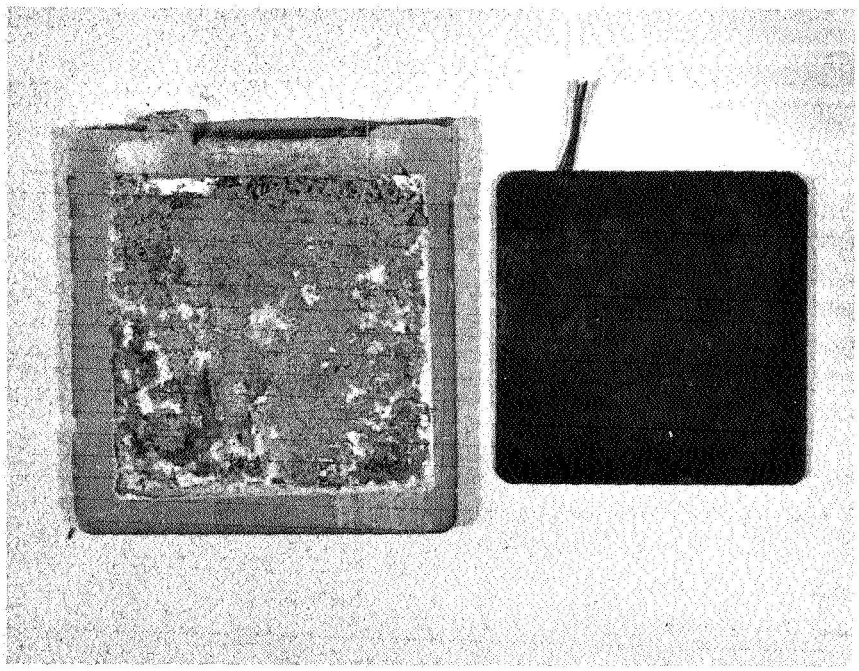
Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 3.6 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 67%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 28%



CS721

Figure B-19. Cell Number 1332

CELL ANALYSIS

Cell No. 1332

Regime 3		Combination 13	
Temperature:	25°C	Binder:	Z
Period:	24 hr.	Ratio:	90/10
Discharge:	1.2 A for 1.2 hr.	Process:	N
Charge:	0.07 A for 22.8 hr.	Additive (PbO%):	1
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.1 Ah
Last Capacity:	Q =	1.2 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	57%
Failure Cycle:	N =	17
Wet Life:	days =	34

Inspection: Separators: No cracks or delam., few stains, signs of Zn pen.

Positive active area: p^+ = N.A.

Negative shape retention: p^- = 100%

Zinc electrode condition: Excellent

Plate Location	Density	Color	Wetness
Top	Hard	Dark Gray	Semi-wet
Bottom	Hard	Dark Gray	Semi-wet

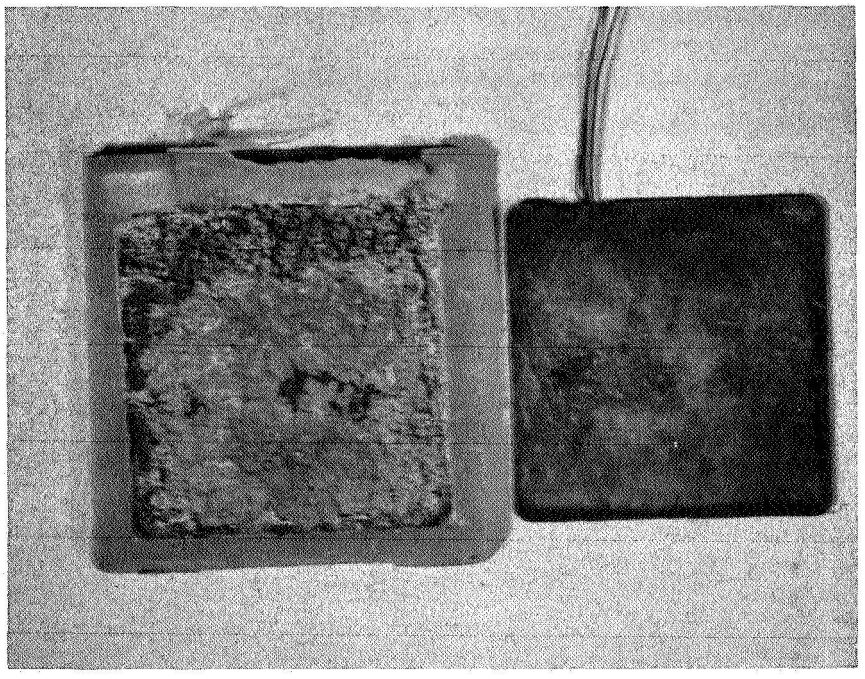
Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 3.9 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 72%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 79%



c5728

Figure B-20. Cell Number 1411

CELL ANALYSIS

Cell No. 1411

Regime 1		Combination 14	
Temperature:	100°C	Binder:	Z
Period:	1 hr.	Ratio:	90/10
Discharge:	0.6 A for 0.5 hr.	Process:	N
Charge:	0.66 A for 0.5 hr.	Additive (PbO%):	2
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.1 Ah
Last Capacity:	Q =	0.6 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	35%
Failure Cycle:	N =	373
Wet Life:	days =	53

Inspection: Separators: No cracks or delam., dark stains, signs of Zn pen.

Positive active area: p^+ = 100%

Negative shape retention: p^- = 80 %

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Blue-Gray	Semi-wet
Bottom	Spongy	Blue-Gray	Semi-wet

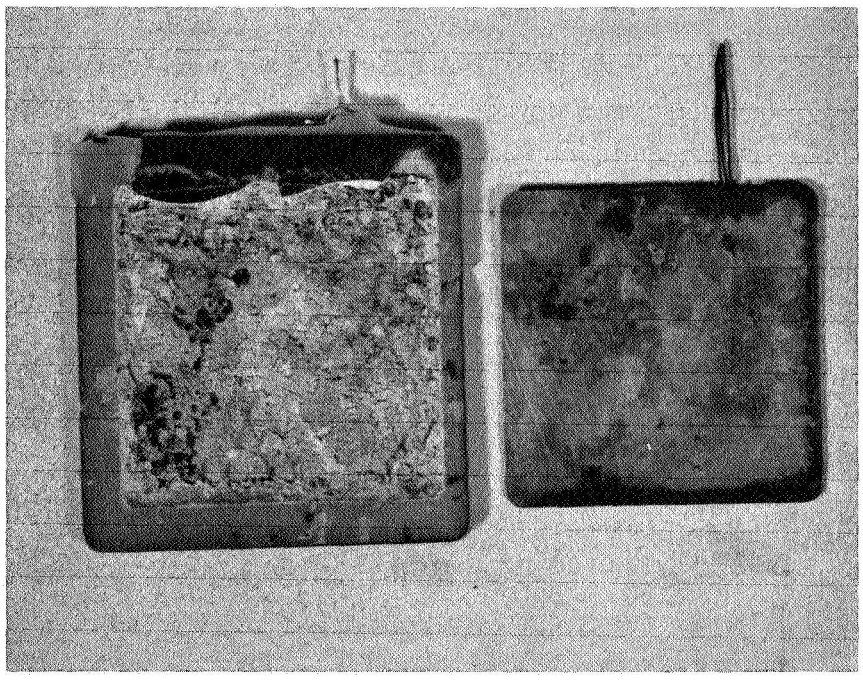
Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 3.1 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 57%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 61%



65729

Figure B-21. Cell Number 1422

CELL ANALYSIS

Cell No. 1422

Regime 2		Combination 14	
Temperature:	25°C	Binder:	Z
Period:	1.5 hr.	Ratio:	90/10
Discharge:	0.9 A for 0.5 hr.	Process:	N
Charge:	0.5 A for 1.0 hr.	Additive (PbO%):	2
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	1.7 Ah
Last Capacity:	Q =	0.5 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	29%
Failure Cycle:	N =	298
Wet Life:	days =	53

Inspection: Separators: No cracks or delam., few stains, signs of Zn pen.

Positive active area: p^+ = 100%

Negative shape retention: p^- = 90%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Hard	Gray	Semi-wet
Bottom	Hard	Gray	Semi-wet

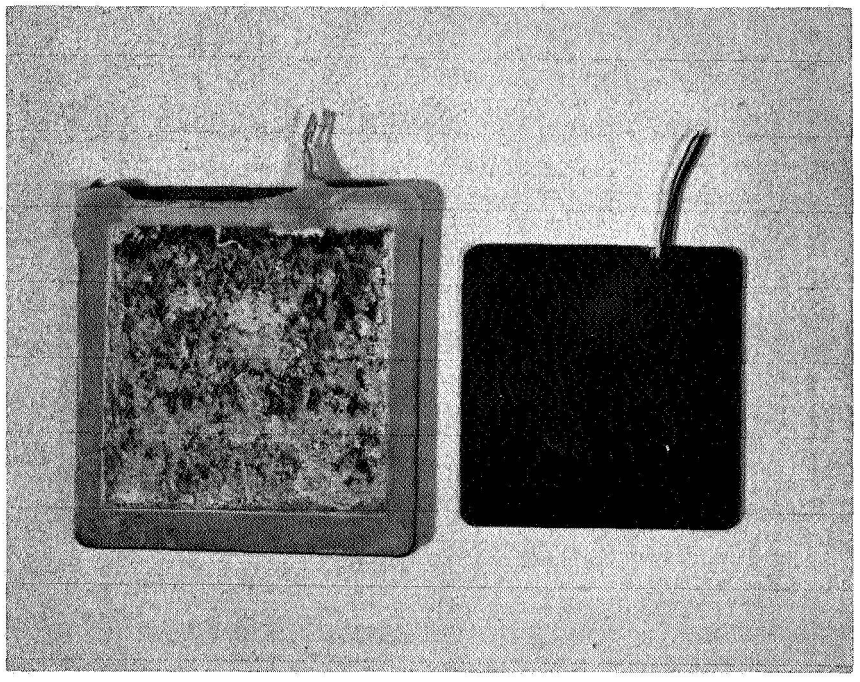
Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 3.6 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 67%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 43%



C5730

Figure B-22. Cell Number 1431

CELL ANALYSIS

Cell No. 1431

Regime 3		Combination 14	
Temperature:	25°C	Binder:	Z
Period:	24 hr.	Ratio:	90/10
Discharge:	1.2 A for 1.2 hr.	Process:	N
Charge:	0.07 A for 22.8 hr.	Additive (PbO%):	2
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.0 Ah
Last Capacity:	Q =	1.1 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	61%
Failure Cycle:	N =	26
Wet Life:	days =	53

Inspection:

Separators: No cracks or delam., few stains, signs of Zn pen.

Positive active area: p^+ = 100%

Negative shape retention: p^- = 100%

Zinc electrode condition: Excellent

Plate Location	Density	Color	Wetness
Top	Hard	Blue-Gray	Semi-wet
Bottom	Hard	Blue-Gray	Semi-wet

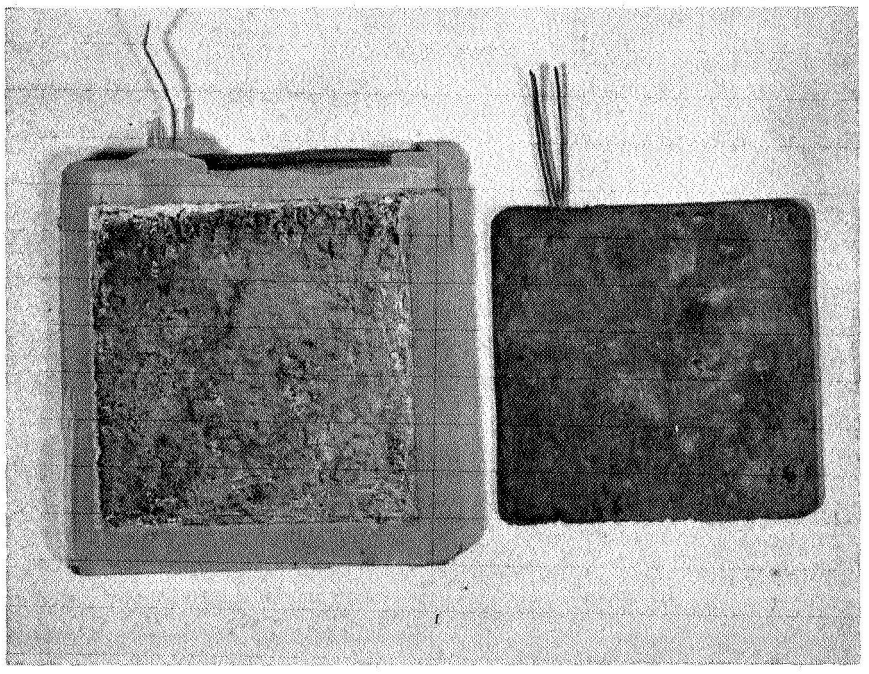
Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 4.6 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 85%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 72%



C5731

Figure B-23. Cell Number 1512

CELL ANALYSIS

Cell No. 1512

Regime 1		Combination 15	
Temperature:	100°C	Binder:	Z
Period:	1 hr.	Ratio:	90/10
Discharge:	0.6 A for 0.5 hr.	Process:	PS
Charge:	0.66 A for 0.5 hr.	Additive (PbO%):	1
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.3 Ah
Last Capacity:	Q =	0.8 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	35%
Failure Cycle:	N =	373
Wet Life:	days =	53

Inspection: Separators: One cracked, no delam., dark stain, signs of Zn pen.

Positive active area: p^+ = 100%

Negative shape retention: p^- = 100%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Blue-Gray	Semi-wet
Bottom	Spongy	Blue-Gray	Semi-wet

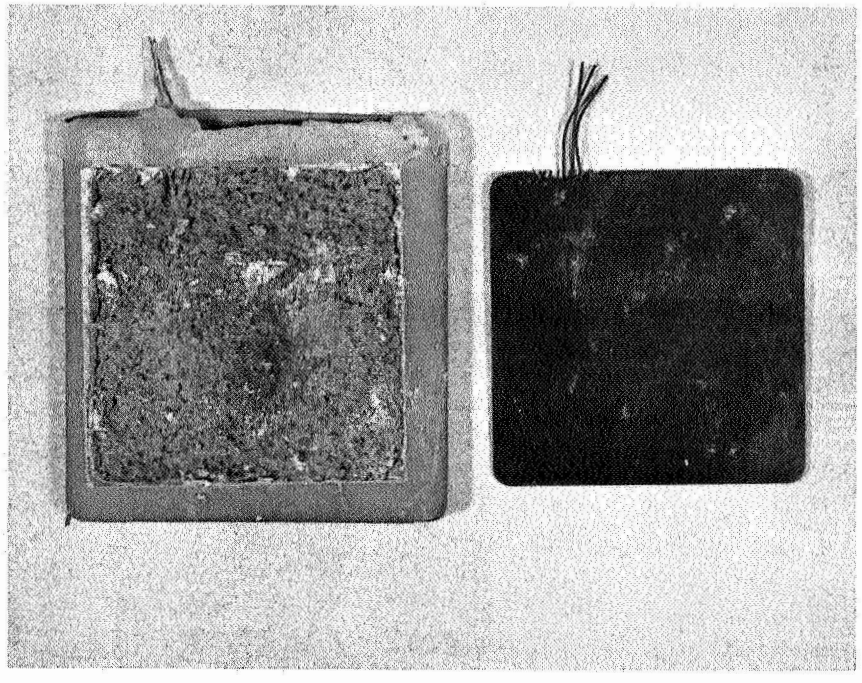
Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 3.3 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 61%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 57%



C5732

Figure B-24. Cell Number 1521

CELL ANALYSIS

Cell No. 1521

Regime 2		Combination 15	
Temperature:	$25^{o}C$	**Binder:**	Z
Period:	1.5 hr.	**Ratio:**	90/10
Discharge:	0.9 A for 0.5 hr.	**Process:**	PS
Charge:	0.5 A for 1.0 hr.	**Additive (PbO%):**	1
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.2 Ah
Last Capacity:	Q =	0.4 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100 =$	18%
Failure Cycle:	N =	122
Wet Life:	days =	34

Inspection: Separators: No cracks or delam., few stains, signs of Zn pen.

Positive active area: p^{+} = N.A.

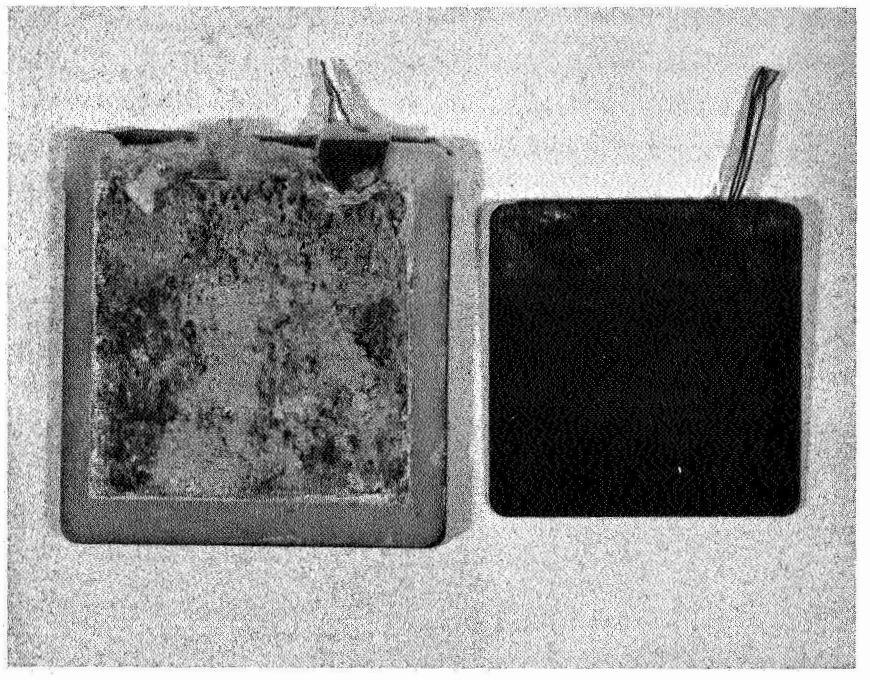
Negative shape retention: p^{-} = 100%

Zinc electrode condition: Excellent

Plate Location	Density	Color	Wetness
Top	Hard	Gray	Semi-wet
Bottom	Hard	Gray	Semi-wet

Analysis:

Original ZnO mass: m_o =	5.4 g
Residual ZnO mass: m =	3.8 g
ZnO retention %: $\zeta = \frac{m}{m_o} \times 100 =$	70%
Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100 =$	26%



C5733

Figure B-25. Cell Number 1533

CELL ANALYSIS

Cell No. 1533

Regime 3		Combination 15	
Temperature:	$25^{o}C$	**Binder:**	Z
Period:	24 hr.	**Ratio:**	90/10
Discharge:	1.2 A for 1.2 hr.	**Process:**	PS
Charge:	0.07 A for 22.8 hr.	**Additive (PbO%):**	1
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.1 Ah
Last Capacity:	Q =	1.2 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	57%
Failure Cycle:	N =	15
Wet Life:	days =	34

Inspection:

Separators: No cracks or delam., few stains, signs of Zn pen.

Positive active area: p^{+} = 100%

Negative shape retention: p^{-} = 100%

Zinc electrode condition: Excellent

Plate Location	Density	Color	Wetness
Top	Hard	Gray	Semi-wet
Bottom	Hard	Gray	Semi-wet

Analysis:

Original ZnO mass: m_o =	5.4 g
Residual ZnO mass: m =	4.0 g
ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ =	74%
Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ =	77%

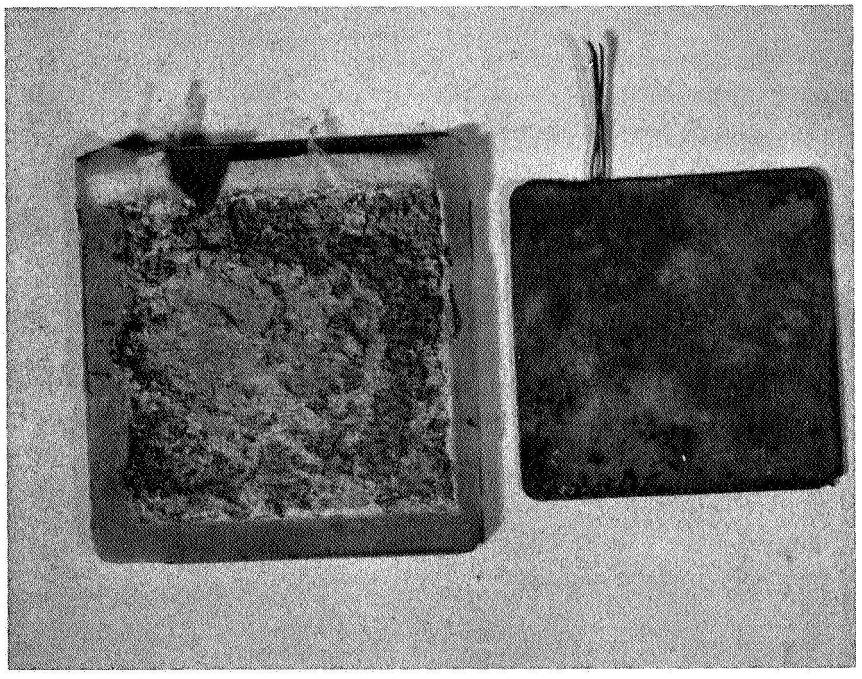


Figure B-26. Cell Number 1611

CELL ANALYSIS

Cell No. 1611

Regime 1		Combination 16	
Temperature:	100°C	Binder:	Z
Period:	1 hr.	Ratio:	90/10
Discharge:	0.6 A for 0.5 hr.	Process:	PS
Charge:	0.66 A for 0.5 hr.	Additive (PbO%):	2
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.1 Ah
Last Capacity:	Q =	1.2 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	57%
Failure Cycle:	N =	373
Wet Life:	days =	49

Inspection: Separators: No cracks or delam., dark stains, signs of Zn pen.

Positive active area: p^+ = 100%

Negative shape retention: p^- = 90%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Hard	Gray	Semi-wet
Bottom	Hard	Gray	Semi-wet

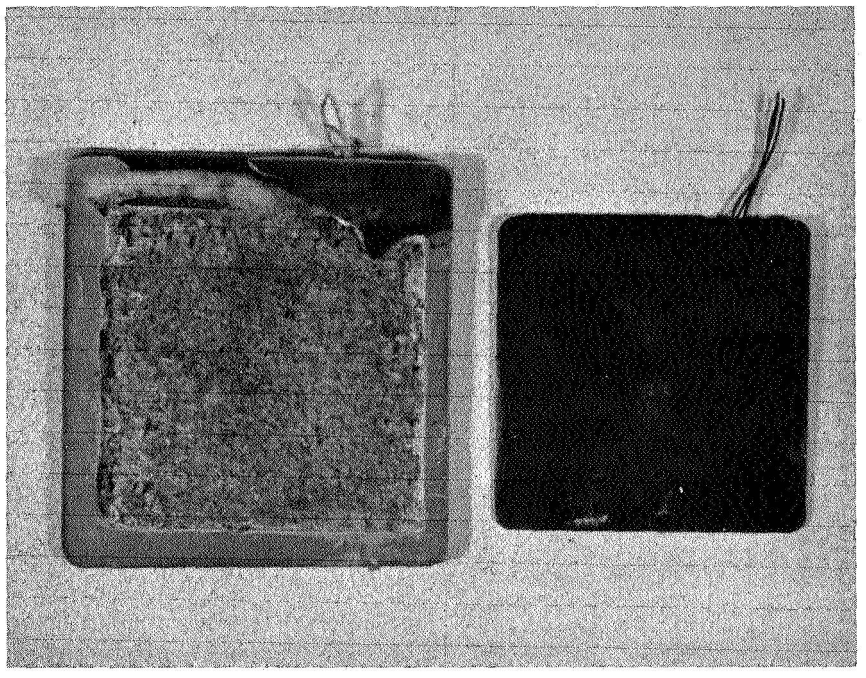
Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 3.3 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 61%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 94%



C5735

Figure B-27. Cell Number 1621

CELL ANALYSIS

Cell No. 1621

Regime 2		Combination 16	
Temperature:	25°C	**Binder:**	Z
Period:	1.5 hr.	**Ratio:**	90/10
Discharge:	0.9 A for 0.5 hr.	**Process:**	PS
Charge:	0.5 A for 1.0 hr.	**Additive (PbO%):**	2
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.1 Ah
Last Capacity:	Q =	0.4 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	19%
Failure Cycle:	N =	124
Wet Life:	days =	30

Inspection: Separators: No cracks or delam., few stains, signs of Zn pen.

Positive active area: p^+ = N.A.

Negative shape retention: p^- = 100%

Zinc electrode condition: Excellent

Plate Location	Density	Color	Wetness
Top	Hard	Gray	Semi-wet
Bottom	Hard	Gray	Semi-wet

Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 3.6 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 67%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 28%

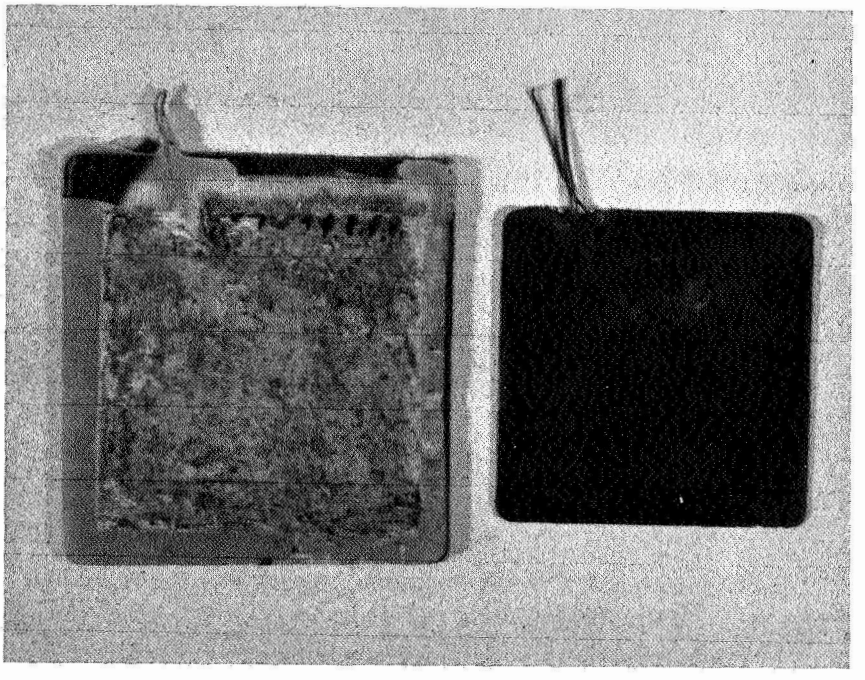


Figure B-28. Cell Number 1633

CELL ANALYSIS

Cell No. 1633

Regime 3		Combination 16	
Temperature:	25°C	Binder:	Z
Period:	24 hr.	Ratio:	90/10
Discharge:	1.2 A for 1.2 hr.	Process:	PS
Charge:	0.07 A for 22.8 hr.	Additive (PbO%):	2
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.1 Ah
Last Capacity:	Q =	1.2 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	57%
Failure Cycle:	N =	15
Wet Life:	days =	30

Inspection: Separators: No cracks or delam., few stains, signs of Zn pen.

Positive active area: p^+ = 100%

Negative shape retention: p^- = 100%

Zinc electrode condition: Excellent

Plate Location	Density	Color	Wetness
Top	Hard	Gray	Semi-wet
Bottom	Hard	Gray	Semi-wet

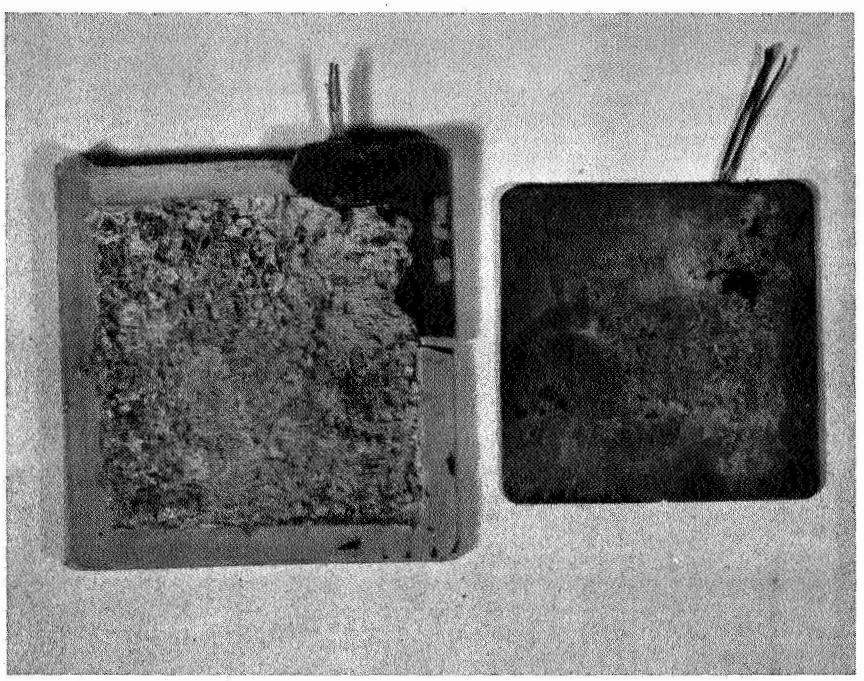
Analysis:

Original ZnO mass: m_o = 5.4 g

Residual ZnO mass: m = 4.2 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 78%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 73%



C5737

Figure B-29. Cell Number 1711

CELL ANALYSIS

Cell No. 1711

Regime 1		Combination 17	
Temperature:	100°C	Binder:	Z
Period:	1 hr.	Ratio:	80/20
Discharge:	0.6 A for 0.5 hr.	Process:	N
Charge:	0.66 A for 0.5 hr.	Additive (PbO%):	1
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.0 Ah
Last Capacity:	Q =	1.3 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	65%
Failure Cycle:	N =	266
Wet Life:	days =	47

Inspection: Separators: No cracks or delam., some stains, signs of Zn pen.

Positive active area: p^+ = 100%

Negative shape retention: p^- = 90%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Blue-Gray	Semi-wet
Bottom	Spongy	Blue-Gray	Semi-wet

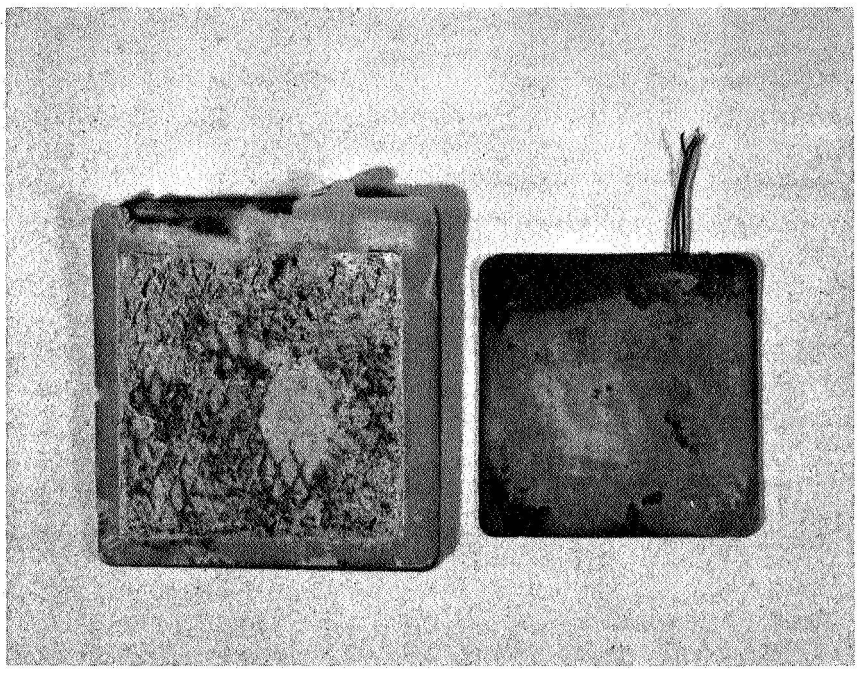
Analysis:

Original ZnO mass: m_o = 4.8 g

Residual ZnO mass: m = 2.7 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 56%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 100%



C5738

Figure B-30. Cell Number 1722

CELL ANALYSIS

Cell No. 1722

Regime 2		Combination 17	
Temperature:	25°C	Binder:	Z
Period:	1.5 hr.	Ratio:	80/20
Discharge:	0.9 A for 0.5 hr.	Process:	N
Charge:	0.5 A for 1.0 hr.	Additive (PbO%):	1
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.2 Ah
Last Capacity:	Q =	0.4 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	18%
Failure Cycle:	N =	170
Wet Life:	days =	47

Inspection:

Separators: No cracks or delam., few stains, signs of Zn pen.

Positive active area: p^+ = N.A.

Negative shape retention: p^- = 80%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Blue-Gray	Semi-wet
Bottom	Hard	Blue-Gray	Semi-wet

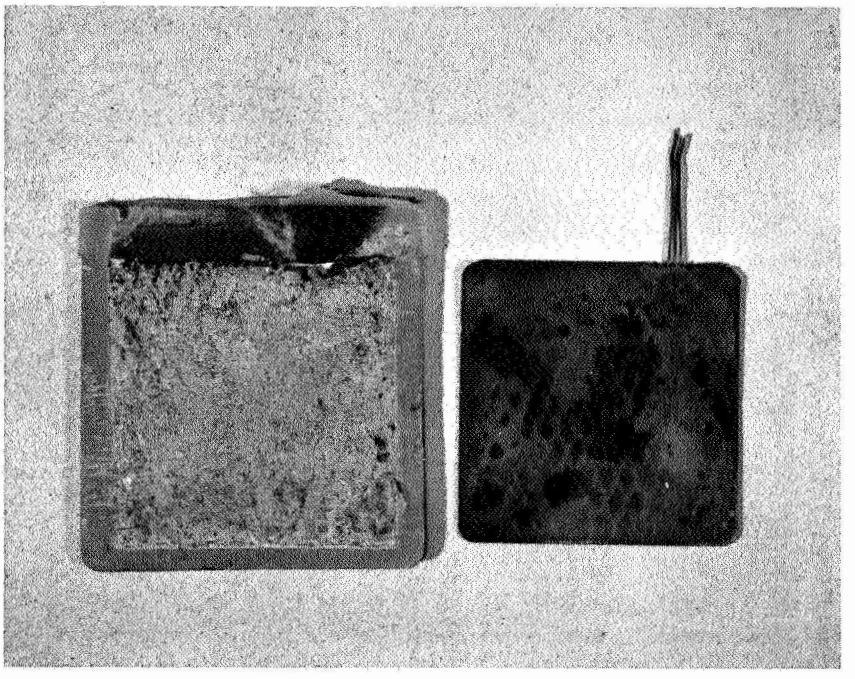
Analysis:

Original ZnO mass: m_o = 4.8 g

Residual ZnO mass: m = 2.8 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 58%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 31%



c5739

Figure B-31. Cell Number 1731

CELL ANALYSIS

Cell No. 1731

Regime 3		Combination 17	
Temperature:	25°C	Binder:	Z
Period:	24 hr.	Ratio:	80/20
Discharge:	1.2 A for 1.2 hr.	Process:	N
Charge:	0.07 A for 22.8 hr.	Additive (PbO%):	1
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.0 Ah
Last Capacity:	Q =	1.3 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	65%
Failure Cycle:	N =	15
Wet Life:	days =	47

Inspection:

Separators: One minute crack, no delam., few stains, signs of Zn pen.

Positive active area: p^+ = 100%

Negative shape retention: p^- = 100%

Zinc electrode condition: Excellent

Plate Location	Density	Color	Wetness
Top	Hard	Blue-Gray	Semi-wet
Bottom	Hard	Blue-Gray	Semi-wet

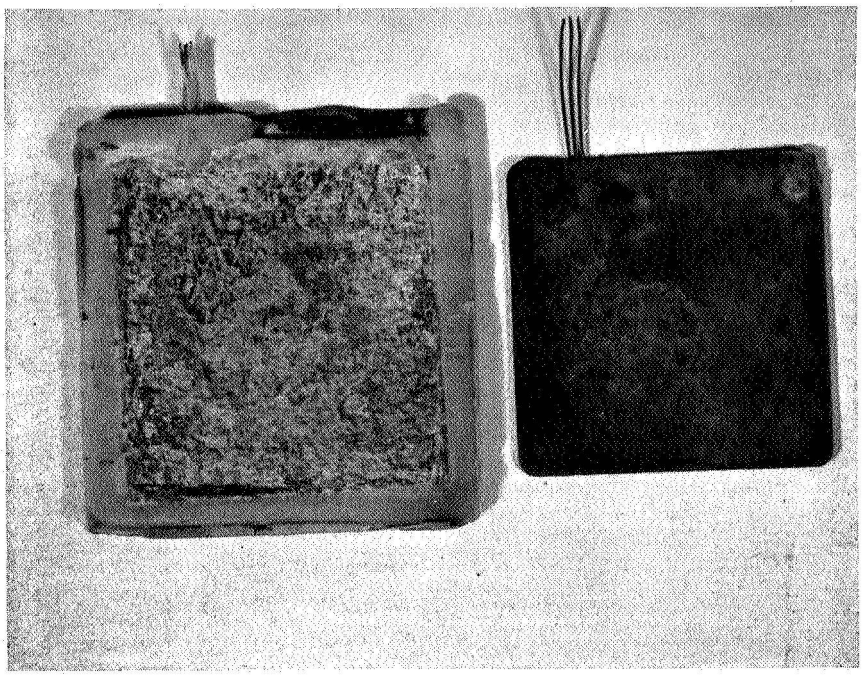
Analysis:

Original ZnO mass: m_o = 4.8 g

Residual ZnO mass: m = 3.7 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 77%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 84%



c5740

Figure B-32. Cell Number 1811

CELL ANALYSIS

Cell No. 1811

Regime 1		Combination 18	
Temperature:	100°C	Binder:	Z
Period:	1 hr.	Ratio:	80/20
Discharge:	0.6 A for 0.5 hr.	Process:	N
Charge:	0.66 A for 0.5 hr.	Additive (PbO%):	2
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	1.8 Ah
Last Capacity:	Q =	1.0 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	56%
Failure Cycle:	N =	266
Wet Life:	days =	47

Inspection:

Separators: No cracks or delam., some stains, signs of Zn pen.

Positive active area: p^+ = 100%

Negative shape retention: p^- = 90%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Gray	Semi-wet
Bottom	Spongy	Gray	Semi-wet

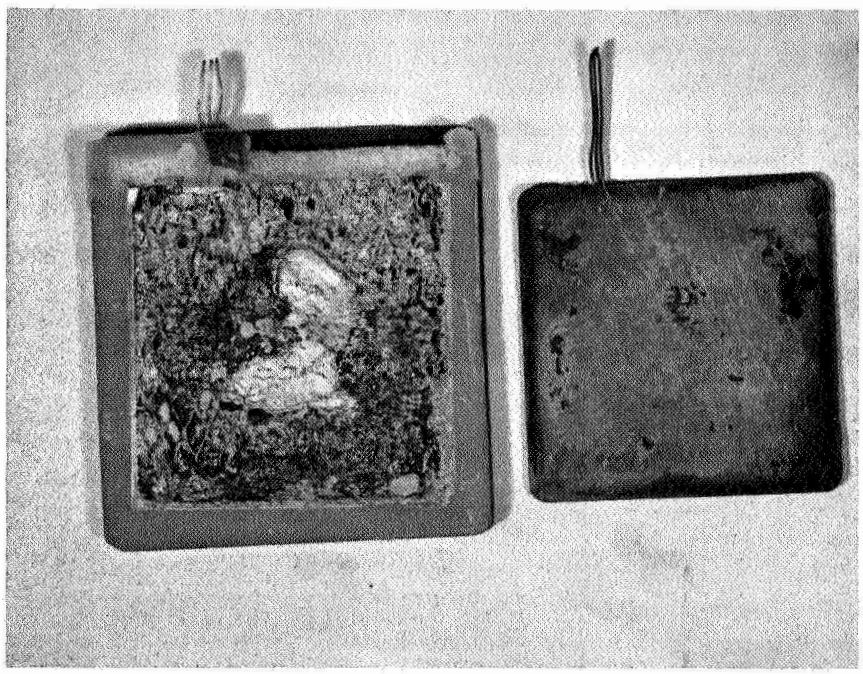
Analysis:

Original ZnO mass: m_o = 4.8 g

Residual ZnO mass: m = 2.7 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 56%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 100%



c5741

Figure B-33. Cell Number 1822

CELL ANALYSIS

Cell No. 1822

Regime 2		Combination 18	
Temperature:	25°C	Binder:	Z
Period:	1.5 hr.	Ratio:	80/20
Discharge:	0.9 A for 0.5 hr.	Process:	N
Charge:	0.5 A for 1.0 hr.	Additive (PbO%):	2
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	1.8 Ah
Last Capacity:	Q =	0.5 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	28%
Failure Cycle:	N =	172
Wet Life:	days =	47

Inspection:

Separators: No cracks or delam., few stains, signs of Zn pen.

Positive active area: p^+ = 100%

Negative shape retention: p^- = 75%

Zinc electrode condition: Fair

Plate Location	Density	Color	Wetness
Top	Spongy	Gray	Semi-wet
Bottom	Hard	Gray	Semi-wet

Analysis:

Original ZnO mass: m_o = 4.8 g

Residual ZnO mass: m = 3.0 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 62%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 45%

CELL ANALYSIS

Cell No. 1831

Regime 3		Combination 18	
Temperature:	25°C	Binder:	Z
Period:	24 hr.	Ratio:	80/20
Discharge:	1.2 A for 1.2 hr.	Process:	N
Charge:	0.07 A for 22.8 hr.	Additive (PbO%):	2
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	1.8 Ah
Last Capacity:	Q =	1.3 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	72%
Failure Cycle:	N =	14
Wet Life:	days =	47

Inspection: Separators: No cracks or delam., few stains.

Positive active area: p^+ = 100%

Negative shape retention: p^- = 80%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Blue-Gray	Semi-wet
Bottom	Hard	Blue-Gray	Semi-wet

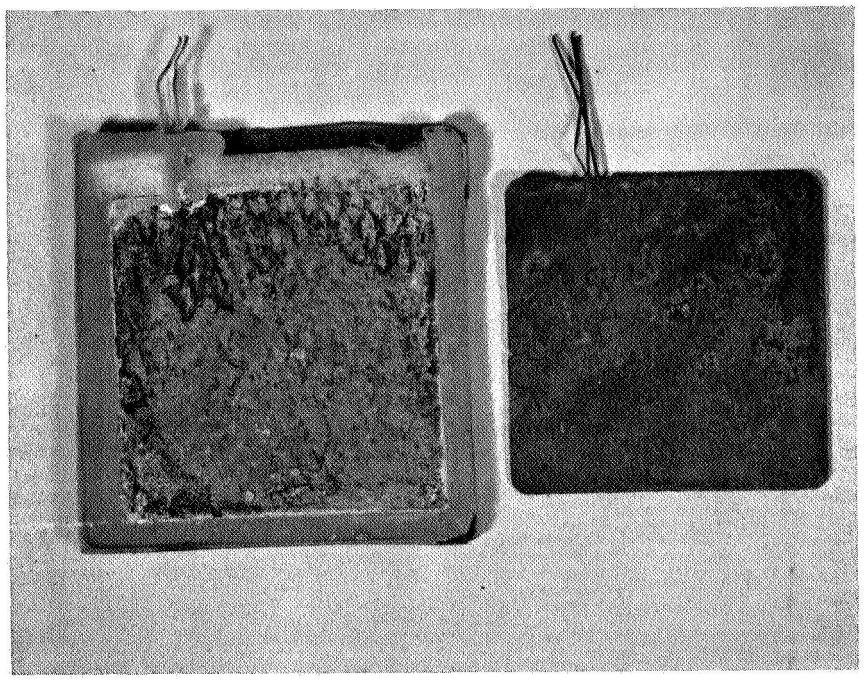
Analysis:

Original ZnO mass: m_o = 4.8 g

Residual ZnO mass: m = 3.9 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 81%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 89%



c5743

Figure B-35. Cell Number 1912

CELL ANALYSIS

Cell No. 1912

Regime 1		Combination 19	
Temperature:	100°C	Binder:	Z
Period:	1 hr.	Ratio:	80/20
Discharge:	0.6 A for 0.5 hr.	Process:	PS
Charge:	0.66 A for 0.5 hr.	Additive (PbO%):	1
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.3 Ah
Last Capacity:	Q =	0.6 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	38%
Failure Cycle:	N =	266
Wet Life:	days =	47

Inspection:

Separators: Both cracked near edge, no delam., some stains, signs of Zn pen.

Positive active area: p^+ = 100%

Negative shape retention: p^- = 100%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Blue-Gray	Semi-wet
Bottom	Spongy	Blue-Gray	Semi-wet

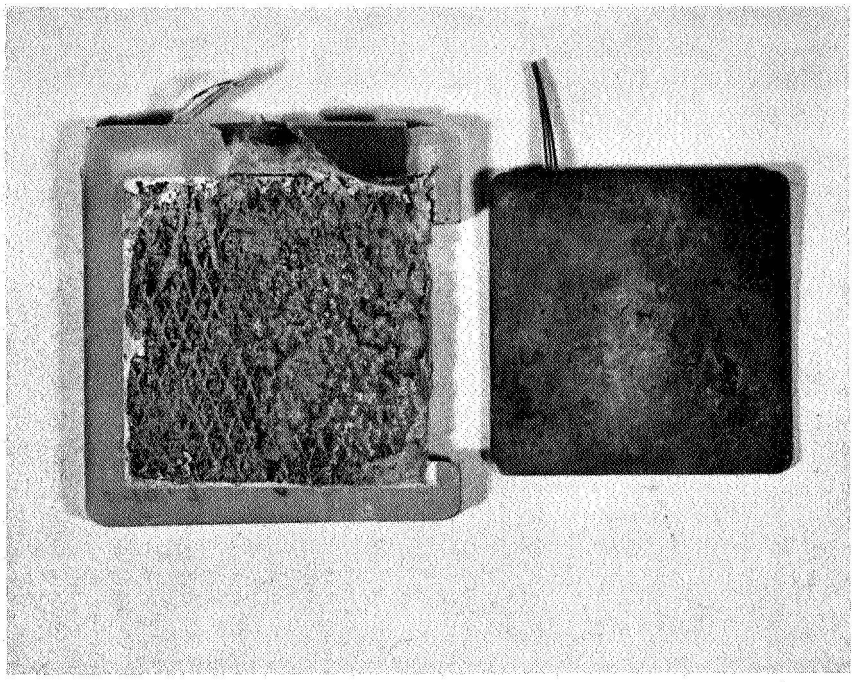
Analysis:

Original ZnO mass: m_o = 4.8 g

Residual ZnO mass: m = 2.6 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 54%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 70%



c5744

Figure B-36. Cell Number 1923

CELL ANALYSIS

Cell No. 1923

Regime 2		Combination 19	
Temperature:	25°C	Binder:	Z
Period:	1.5 hr.	Ratio:	80/20
Discharge:	0.9 A for 0.5 hr.	Process:	PS
Charge:	0.5 A for 1.0 hr.	Additive (PbO%):	1
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.3 Ah
Last Capacity:	Q =	0.5 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	22%
Failure Cycle:	N =	105
Wet Life:	days =	40

Inspection: Separators: No cracks or delam., few stains, signs of Zn pen.

Positive active area: p^+ = N.A.

Negative shape retention: p^- = 75%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Hard	Gray	Semi-wet
Bottom	Hard	Gray	Semi-wet

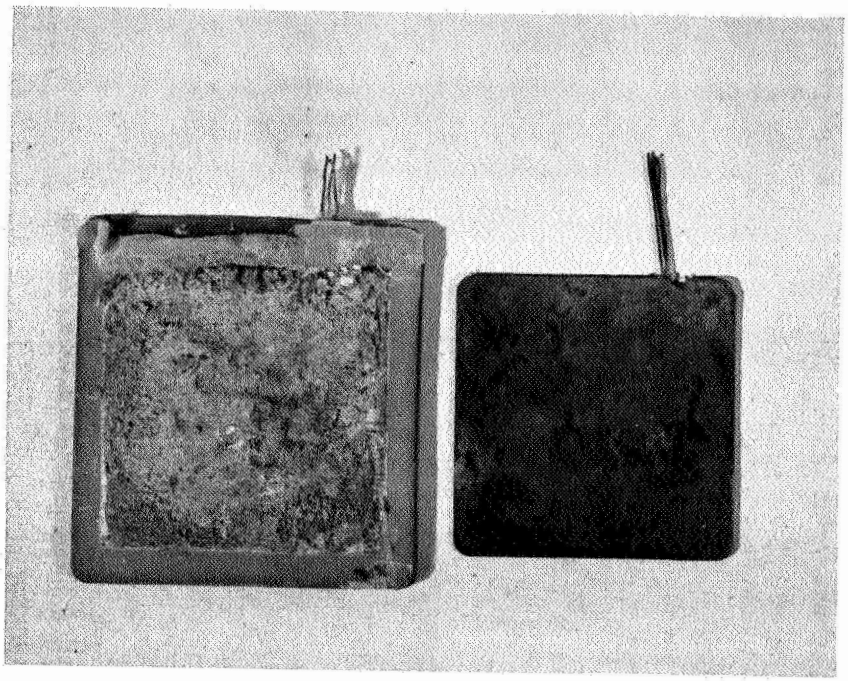
Analysis:

Original ZnO mass: m_o = 4.8 g

Residual ZnO mass: m = 3.1 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 65%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 34%



c5745

Figure B-37. Cell Number 1931

CELL ANALYSIS

Cell No. 1931

Regime 3		Combination 19	
Temperature:	25°C	**Binder:**	Z
Period:	24 hr.	**Ratio:**	80/20
Discharge:	1.2 A for 1.2 hr.	Process:	PS
Charge:	0.07 A for 22.8 hr.	Additive (PbO%):	1
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.3 Ah
Last Capacity:	Q =	1.2 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	52%
Failure Cycle:	N =	14
Wet Life:	days =	47

Inspection:

Separators: No cracks or delam., few stains, signs of Zn pen.

Positive active area: p^+ = 100%

Negative shape retention: p^- = 100%

Zinc electrode condition: Excellent

Plate Location	Density	Color	Wetness
Top	Hard	Blue-Gray	Semi-wet
Bottom	Hard	Blue-Gray	Semi-wet

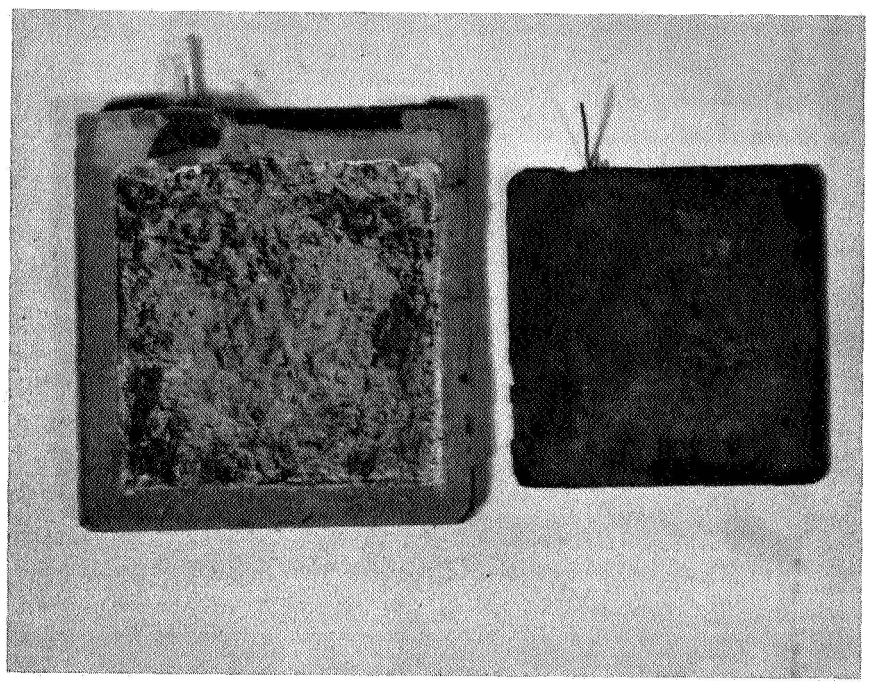
Analysis:

Original ZnO mass: m_o = 4.8 g

Residual ZnO mass: m = 4.0 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 83%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 63%



C5746

Figure B-38. Cell Number 2011

CELL ANALYSIS

Cell No. 2011

Regime 1		Combination 20	
Temperature:	$100^{o}C$	**Binder:**	Z
Period:	1 hr.	**Ratio:**	80/20
Discharge:	0.6 A for 0.5 hr.	**Process:**	PS
Charge:	0.66 A for 0.5 hr.	**Additive (PbO%):**	2
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.2 Ah
Last Capacity:	Q =	0.7 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	32%
Failure Cycle:	N =	266
Wet Life:	days =	47

Inspection: Separators: Both cracked near edge, no delam., some stains, signs of Zn pen.

Positive active area: p^{+} = 100%

Negative shape retention: p^{-} = 100%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Blue-Gray	Semi-wet
Bottom	Spongy	Blue-Gray	Semi-wet

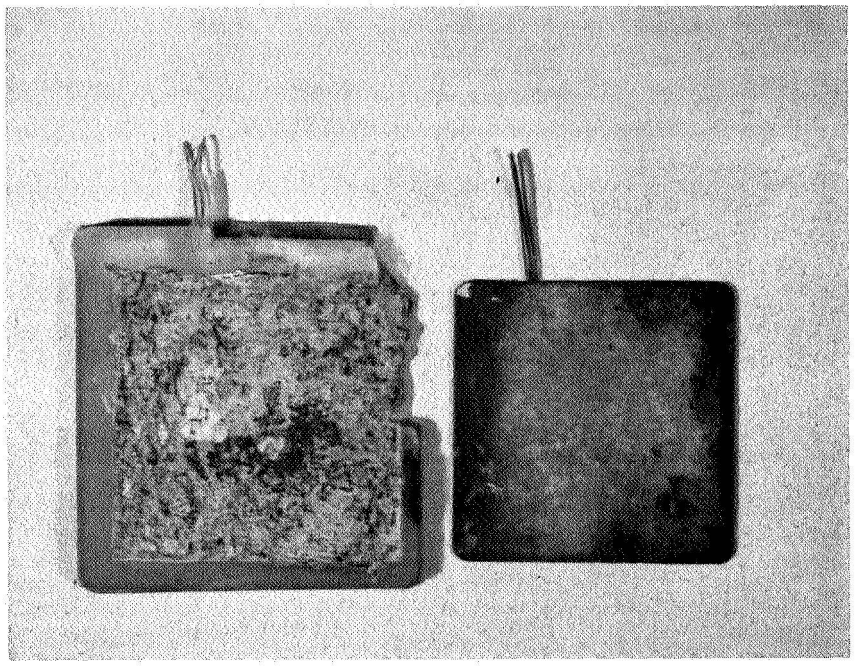
Analysis:

Original ZnO mass: m_o = 4.8 g

Residual ZnO mass: m = 2.6 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 54%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 59%



C5747

Figure B-39. Cell Number 2022

CELL ANALYSIS

Cell No. 2022

Regime 2		Combination 20	
Temperature:	$25^{o}C$	**Binder:**	Z
Period:	1.5 hr.	**Ratio:**	80/20
Discharge:	0.9 A for 0.5 hr.	**Process:**	PS
Charge:	0.5 A for 1.0 hr.	**Additive (PbO%):**	2
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.3 Ah
Last Capacity:	Q =	0.4 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	17%
Failure Cycle:	N =	169
Wet Life:	days =	47

Inspection: Separators: No cracks or delam., few stains, signs of Zn pen.

Positive active area: p^{+} = N.A.

Negative shape retention: p^{-} = 90%

Zinc electrode condition: Good

Plate Location	Density	Color	Wetness
Top	Spongy	Blue-Gray	Semi-wet
Bottom	Hard	Blue-Gray	Semi-wet

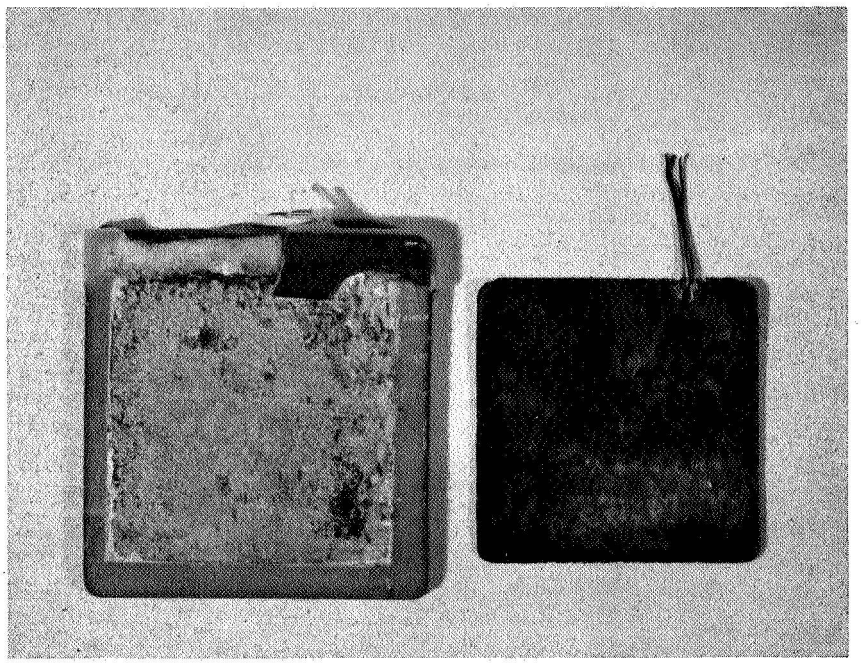
Analysis:

Original ZnO mass: m_o = 4.8 g

Residual ZnO mass: m = 2.6 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 54%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 31%



c5748

Figure B-40. Cell Number 2032

CELL ANALYSIS

Cell No. 2032

Regime 3		Combination 20	
Temperature:	25°C	**Binder:**	Z
Period:	24 hr.	**Ratio:**	80/20
Discharge:	1.2 A for 1.2 hr.	**Process:**	PS
Charge:	0.07 A for 22.8 hr.	**Additive (PbO%):**	2
		Grid:	5 Ag 14-1/0
		Design:	(-) W

Original Capacity:	Q_o =	2.2 Ah
Last Capacity:	Q =	1.1 Ah
Capacity Retention %:	$q = \frac{Q}{Q_o} \times 100$ =	50%
Failure Cycle:	N =	14
Wet Life:	days =	47

Inspection: Separators: One minute crack, no delam., few stains, some Zn pen.

Positive active area: p^+ = 100%

Negative shape retention: p^- = 100%

Zinc electrode condition: Excellent

Plate Location	Density	Color	Wetness
Top	Spongy	Blue-Gray	Semi-wet
Bottom	Spongy	Blue-Gray	Semi-wet

Analysis:

Original ZnO mass: m_o = 4.8 g

Residual ZnO mass: m = 3.8 g

ZnO retention %: $\zeta = \frac{m}{m_o} \times 100$ = 79%

Final-to-original utilization ratio (%): $\eta = \frac{q}{\zeta} \times 100$ = 63%

DISTRIBUTION LIST

National Aeronautics & Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: Dr. L. Rosenblum (MS 302-1)
H. J. Schwartz (MS 309-1)
Dr. J. S. Fordyce (MS 6-1)
J. E. Dilley (MS 500-309)
Technology Utilization Office (MS 3-19)
W. J. Nagle (MS 309-1)
D. G. Soltis (MS 309-1)
V. Hlavin (MS 3-14)
Library (MS 60-3)
Report Control (MS 5-5)
Dr. B. Lubarsky (MS 3-3)
W. A. Robertson (MS 309-1)
J. Toma (MS 302-1)

National Aeronautics & Space Administration
Scientific & Technical Information Division
Washington, D. C. 20546
Attn: RNW/E. M. Cohn
RNW/Arvin Smith
FC/A. M. Greg Andrus
RN/William H. Woodward
UT/Dr. S. J. Glassman

National Aeronautics & Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771
Attn: Thomas Hennigan, Code 716.2
Gerald Halpert, Code 735
Joseph Sherfey, Code 735
Louis Wilson, Code 450

National Aeronautics & Space Administration
Langley Research Center
Instrument Research Division
Hampton, Virginia 23365
Attn: John L. Patterson, MS 472
M. B. Seyffert, MS 112

National Aeronautics & Space Administration
Geo C. Marshall Space Flight Center
Huntsville, Alabama 35812
Attn: Philip Youngblood
Richard Boehme (R-ASTR-EP)
C. B. Graff (S&E-ASTR-EP)

National Aeronautics & Space Administration
Manned Spacecraft Center
Houstin, Texas 77058
Attn: William K. Dusenbury
Prop. & Energy Systems Branch
Bldg, Site 1
Attn: W. E. Rice (EP-5)
Attn: Robert Cohen
Gemini Project Office
Attn: Forrest E. Eastman (EE-4)

National Aeronautics & Space Administration
Washington, D. C. 20546
Attn: Office of Technology Utilization

National Aeronautics & Space Administration
Langley Research Center
Langley Station
Hampton, Virginia 23365
Attn: S. T. Pererson/Harry Ricker

National Aeronautics & Space Administration
Scientific & Technical Information
Center: Input
P. O. Box 33
College Park, Maryland 20740

National Aeronautics & Space Administration
Ames Research Center
Pioneer Project
Moffett Field, California 94035
Attn: Arthur Wilber/A. S. Hertzog

National Aeronautics & Space Administration
Ames Research Center
Moffett Field, California 94035
Attn: Jon Rubenzer
Code PBS, MS 244-2

National Aeronautics & Space Administration
Electronics Research Center
575 Technology Square
Cambridge, Massachusetts 02139
Attn: Dr. Sol Gilman, Code CPE

Jet Propulsion Laboratory
4800 Grove Drive
Pasadena, California 91103
Attn: Mr. Paul Goldsmith (MS 198-233)
Dr. R. Lutwack (MS 190-220)

Department of the Army

U. S. Army Mobility Equipment R&D Center
MERDC
Fort Belvoir, Virginia 22060
Electro Technology Lab
Energy Conversion Research Division

Commanding General
U. S. Army Weapons Command
Attn: AMSWE-RDR, Mr. G. Reinsmith
Rock Island Arsenal
Rock Island, Illinois 61201

U. S. Army Research Office
Box CM, Duke Station
Durham, North Carolina 27706
Attn: Dr. Wilhelm Jorgensen

U. S. Army Research Office
Chief, R&D
Department of the Army
3D442, The Pentagon
Washington, D. C. 20546

U. S. Army Natick Laboratories
Clothing and Organic Materials Division
Natick, Massachusetts 01762
Attn: L. A. Spano

Commanding Officer
U. S. Army Electronics R&D Labs
Fort Monmouth, New Jersey 07703
Attn: Power Sources Division (SELRA/PS)

Army Materiel Command
Research Division
AMCRD-RSCM-T-7
Washington, D. C. 20315
Attn: John W. Crellin

Army Materiel Command
Development Division
AMCRD-DE-MO-P
Washington, D. C. 20315
Attn: Marshall D. Aiken

U. S. Army TRECOM
Fort Eustis, Virginia 23604
Attn: Leonard M. Bartone (SMOFE-ASE)
Dr. R. L. Eshols (SMOFE-PSG)

U. S. Army Mobility Command
Research Division
Warrent, Michigan 48090
Attn: O. Renius (AMSMO-RR)

Harry Diamond Laboratories
Room 300, Building 92
Conn. Ave & Van Ness St., N. W.
Washington, D. C. 20438
Attn: Nathan Kaplan

Department of the Navy

Office of Naval Research
Washington, D. C. 20360
Attn: Director, Power Program
Code 473

Office of Naval Research
Department of the Navy
Washington, D. C. 20460
Attn: H. W. Fox (Code 472)

Naval Research Laboratory
Washington, D. C. 20390
Attn: Dr. J. C. White, Code 6160

Naval Ship R&D Center
Annapolis, Maryland 21402
Attn: J. H. Harrision, Code M760

U. S. Naval Observatory
Attn: Robt. E. Trumbule
STIC, Bldg. 52
Washington, D. C. 20390

Naval Air Systems Command
Department of the Navy
Washington, D. C. 20360
Attn: Milton Knight (Code AIR-340C)

Commanding Officer
(Code QEWE, E. Bruess/H. Schultz)
U. S. Naval Ammunition Depot
Crane, Indiana 47522
Attn: D. Miley, Code QEWE

Naval Weapons Center
Corona Laboratories
Corona, California 91720
Attn: William C. Spindler (Code 441)

Naval Ordnance Laboratory
Silver Spring, Maryland 20910
Attn: Philip D. Cole (Code 232)

Naval Ship Engineering Center
Washington, D. C. 20360
Attn: C. F. Viglotti (Code 6157D)

Bureau of Naval Weapons
Department of the Navy
Washington, D. C. 20360
Attn: Whitewall T. Beatson
(Code RAAE-52)

Naval Ship Systems Command
Washington, D. C. 20360
Attn: Bernard B. Rosenbaum
Code 03422

Department of the Air Force

Aero Propulsion Laboratory
Wright-Patterson AFB, Ohio 45433
Attn: James E. Cooper, APIP-1

AF Cambridge Research Laboratory
Attn: CRFE
L. G. Hanscom Field
Bedford, Massachusetts 01731
Attn: Dr. R. Payne

AF Cambridge Research Laboratory
L. G. Hanscom Field
Bedford, Massachusetts 01731
Attn: Francis X. Doherty, CRE
Edward Raskind (Wing F)

Headquarters, U. S. Air Force (AFRDR-AS)
Washington, D. C. 20325
Attn: Major G. Starkey

Headquarters, U. S. Air Force (AFRDR-AS)
Washington, D. C. 20325
Attn: Lt. Col. William G. Alexander

Rome Air Development Center, ESD
Attn: Frank J. Mollura (EMEAM)
Griffis AFB, New York 13442

Space Systems Division
Los Angeles Air Force Station
Los Angeles, California 90045
Attn: SSSD

Other Government Agencies

National Bureau of Standards
Washington, D. C. 20234
Attn: Dr. W. J. Hamer

National Bureau of Standards
Washington, D. C. 20234
Attn: Dr. A. Brenner

Office, Sea Warfare System
The Pentagon
Washington, D. C. 20310
Attn: G. B. Wareham

U. S. Atomic Energy Commission
Auxiliary Power Branch (SNAP)
Division of Reactor Development
Washington, D. C. 20325
Attn: Lt. Col. George H. Ogburn, Jr.

Lt. Col. John H. Anderson
Advanced Space Reactor Branch
Division of Reactor Development
U. S. Atomic Energy Commission
Washington, D. C. 20325

Mr. Donald A. Hoatson
Army Reactors, DRD
U. S. Atomic Energy Commission
Washington, D. C. 20545

Bureau of Mines
4800 Forbes Avenue
Pittsburgh, Pennsylvania 15213
Attn: Dr. Irving Wender

Clearing House for Scientific &
Technical Information
5285 Port Royal Road
Springfield, Virginia 22151

Private Organizations

Aerojet-General Corporation
Chemical Products Division
Azusa, California 91702
Attn: William H. Johnson

Aerojet-General Corporation
Von Karman Center
Bldg. 312, Dept. 3111
Azusa, California 91703
Attn: Mr. Russ Fogle

Allis Chalmers Manufacturing Company
Advanced Electrochem Products Division
P. O. Box 540
Green Dale, Wisconsin 53129
Attn: Dr. H. J. Seim

Aeronutronic Division of Philco Corporation
Technical Information Services
Ford Road
Newport Beach, California 92663

Aerospace Corporation
P. O. Box 95085
Los Angeles, California 90045
Attn: Library Acquisition Group

Aerospace Corporation
Systems Design Division
2350 East El Segundo Boulevard
El Segundo, California 90246
Attn: John G. Krisilas

Allis-Chalmers Manufacturing Company
1100 South 70th Street
Milwaukee, Wisconsin 53201
Attn: Dr. P. Joyner

A. M. F.
Attn: R. J. Mosny/M. S. Mintz
689 Hope Street
Stamford, Connecticut 06907

American University
Mass. & Nebraska Avenue, N. W.
Washington, D. C. 20016
Attn: Dr. R. T. Foley
Chemistry Department

Arthur D. Little, Inc.
Acorn Park
Cambridge, Massachusetts 02140
Attn: Dr. James D. Birkett

Atomics International Division
North American Aviation, Inc.
8900 DeSota Avenue
Canoga Park, California 91304
Attn: Dr. H. L. Recht

Battelle Memorial Institute
505 King Avenue
Columbus, Ohio 43201
Attn: Dr. C. L. Faust

Bell Laboratories
Murray Hill, New Jersey 07974
Attn: U. B. Thomas/D. O. Feder

American Cyanamid Company
1937 W. Main Street
Stamford, Connecticut 06902
Attn: Dr. R. A. Haldeman

The Boeing Company
P. O. Box 3999
Seattle, Washington 98124
Attn: Sid Gross, MS 85-86, 2-7814

Borden Chemical Company
Central Research Laboratory
P. O. Box 9524
Philadelphia, Pennsylvania 19124

Burgess Battery Company
Foot of Exchange Street
Freeport, Illinois 61032
Attn: Dr. Howard J. Strauss

C & D Batteries
Division of Electric Autolite Company
Conshohocken, Pennsylvania 19428
Attn: Dr. Eugene Willihnganz

Calvin College, Science Bldg.
3175 Burton Street, S.E.
Grand Rapids, Michigan 49506
Attn: Professor T. P. Dirkse

Communications Satellite Corporation
1835 K Street, N.W.
Washington, D. C. 20036
Attn: Mr. Robt. Strauss

Catalyst Research Corporation
6101 Falls Road
Baltimore, Maryland 21209
Attn: Dr. H. Goldsmith

ChemCell Inc.
150 Dey Road
Wayne, New Jersey 07470
Attn: Peter D. Richman

Cubic Corporation
9233 Balboa Avenue
San Diego, California 92123
Attn: Librarian

Delco Remy Division
General Motors Corporation
2401 Columbus Avenue
Anderson, Indiana 46011
Attn: J. A. Keralla

Bellcomm, Inc.
955 Lenfant Plaza North, S.W.
Washington, D. C. 20024
Attn: B. W. Moss

McDonnell Douglas Corporation
Astropower Laboratory
2121 Campus Drive
Newport Beach, California 92663
Attn: Dr. George Moe

Dynatech Corporation
17 Tudor Street
Cambridge, Massachusetts 02139
Attn: R. L. Wentworth

Bellcomm
1100-17th Street, N.W.
Washington, D. C. 20036
Attn: B. W. Moss

Eagle-Picher Company
Post Office Box 47
Joplin, Missouri 64801
Attn: E. P. Broglio

ESB Inc.
Post Office Box 11097
Raleigh, North Carolina 27604
Attn: Director of Engineering

Electromite Corporation
2117 South Anne Street
Santa Ana, California 92704
Attn: R. H. Sparks

ESB Inc.
Research Center
19 West College Avenue
Yardley, Pennsylvania 19067
Attn: Librarian

Electrochemical & Water Desalination Technology
13401 Kootenay Drive
Santa Ana, California 92705
Attn: Dr. Carl Berger

Electrochimica Corporation
1140 O'Brien Drive
Menlo Park, California 94025
Attn: Dr. Morris Eisenberg

Electro-Optical Systems, Inc.
300 North Halstead
Pasadena, California 91107
Attn: Martin Klein

E. I. DuPont Nemours & Co.
Engineering Materials Laboratory
Wilmington, Delaware 19898
Attn: J. M. Williams
Bldg. 304

Energetics Science, Inc.
4461 Bronx Blvd.
New York, New York 10470
Attn: Dr. H. G. Oswin

Elgin National Watch Company
107 National Street
Elgin, Illinois 60120
Attn: T. Boswell

Emhard Corporation
Box 1620
Hartford, Connecticut 06102
Attn: Dr. W. P. Cadogan

Engelhard Industries, Inc.
497 Delancy Street
Newark, New Jersey 07105
Attn: Dr. J. G. Cohn

Dr. Arthur Fleischer
466 South Center Street
Orange, New Jersey 07050

General Electric Company
Post Office Box 43
Schenectady, New York 12301
Attn: Dr. R. P. Hamlen

General Electric Company
Missile & Space Division
Spacecraft Department
P. O. Box 8555
Philadelphia, Pennsylvania 19101
Attn: K. L. Hanson, Room M-2614

General Electric Company
Battery Business Section
P. O. Box 114
Gainesville, Florida 32601
Attn: W. H. Roberts
Dr. R. L. Hadley

General Electric Company
Research & Development Center
Post Office Box 8
Schenectady, New York 12301
Attn: Whitney Library

Dr. P. L. Howard
Centerville, Maryland 21617

General Telephone & Electronics Labs
Bayside, New York 1352
Attn: Dr. Paul Goldberg

Gould Ionics, Inc.
P. O. Box 1377
Canoga Park, California 91304
Attn: Dr. J. E. Oxley

Globe-Union, Inc.
P. O. Box 591
Milwaukee, Wisconsin 53201
Attn: John R. Thomas

Gould-National Batteries, Inc.
Engineering & Research Center
2630 University Avenue, S. E.
Minneapolis, Minnesota 55418
Attn: D. L. Douglas

Gulton Industries
Alkaline Battery Division
1 Gulton Street
Metuchen, New Jersey 08840
Attn: Dr. H. N. Seiger

Grumman Aircraft
Plant 35, OAAP Project
Bethpage, Long Island, N. Y. 11714
Attn: J. S. Caraceni

Hughes Aircraft Corporation
Centinda Avenue & Teale Street
Culver City, California 90230
Attn: T. V. Carvey

G. & W. H. Corson, Inc.
Plymouth Meeting
Pennsylvania 19462
Attn: Dr. L. J. Minnick

Hughes Aircraft Corporation
Bldg. 366, M.S. 524
El Segundo, California 90245
Attn: M. E. Ellison

Hughes Research Labs. Corp.
3011 Malibu, California 90265
Attn T. M. Hahn

ITT Federal Laboratories
500 Washington Avenue
Nutley, New Jersey 07110
Attn: Dr. P. E. Lighty

ITT Research Institute
10 West 35th Street
Chicago, Illinois 60616
Attn: Dr. H. T. Francis

Institute for Defense Analyses
R&E Support Division
400 Army-Navy Drive
Arlington, Virginia 22202
Attn: Mr. R. Hamilton

Institute for Defense Analyses
R&E Support Division
400 Army-Navy Drive
Arlington, Virginia 22202
Attn: Dr. R. Briceland

Idaho State University
Department of Chemistry
Pocatello, Idaho 83201
Attn: Dr. G. Myron Arcand

Institute of Gas Technology
State and 34th Street
Chicago, Illinois 60616
Attn: B. S. Baker

International Nickel Company
1000-16th Street, N.W.
Washington, D. C. 20036
Attn: Wm. C. Mearns

John Hopkins University
Applied Physics Laboratory
8621 Georgia Avenue
Silver Spring, Maryland 20910
Attn: Richard E. Evans

Johns-Manville R&E Center
Post Office Box 159
Manville, New Jersey 08835
Attn: J. S. Parkinson

Leesona Moos Laboratories
Lake Success Park, Community Drive
Great Neck, New York 11021
Attn: Dr. A. Moos

Honeywell Inc.
Livingston Electronic Laboratory
Route 309
Montgomeryville, Pennsylvania 18936

Lockheed Missiles & Space Company
Post Office Box 504
Sunnyvale, California
Attn: R. E. Corbett
Dept. 62-14, Bldg. 154

Lockheed Missiles & Space Company
Dept. 62-30
3251 Hanover Street
Palo Alto, California 94304
Attn: J. E. Chilton

Lockheed Missiles & Space Company
Technical Information Center
3251 Hanover Street
Palo Alto, California 93404

Mallory Battery Company
South Broadway & Sunnyside Lane
Tarrytown, New York 10591
Attn: R. R. Clune

P. R. Mallory & Company, Inc.
Northwest Industrial Park
Burlington, Massachusetts 01803
Attn: Dr. Per Bro

P. R. Mallory & Company, Inc.
Technical Services Laboratory
Indianapolis, Indiana 46206
Attn: A. S. Doty

P. R. Mallory & Company, Inc.
3029 E. Washington Street
Indianapolis, Indiana 46206
Attn: Technical Librarian

Marquardt Corporation
16555 Saticoy Street
Van Nuys, California 91406
Attn: Dr. H. G. Krull

Martin Company
Electronics Research Department
P. O. Box 179
Denver, Colorado 80201
Attn: William B. Collins, MS 1620
Attn: M. S. Imanura, MS 8840

Material Research Corporation
Orangeburg, New York 10962
Attn: V. E. Adler

Mauchly Systems, Inc.
Montgomeryville Industrial Park
Pennsylvania 18936
Attn: John H. Waite

Melpar
Technical Information Center
7700 Arlington Boulevard
Falls Church, Virginia 22046

McDonnell Douglas Corporation
3000 Ocean Park Blvd.
Santa Monica, California 90406
Attn: A. D. Tonelli, MS-7C

North American Rockwell
Autonetics Division
P. O. Box 4181
Anaheim, California 92803
Attn: R. F. Fogle GF1G

Metals and Controls Division
Texas Instruments, Inc.
34 Forrest Street
Attleboro, Massachusetts 02703
Attn: Dr. E. M. Jost/Dr. J. W. Ross

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: Physical Science Laboratory

North American Aviation, Inc.
12214 Lakewood Boulevard
Downey, California 90241
Attn: Burton M. Otzinger

North American Aviation, Inc.
Rocketdyne Division
6633 Canoga Avenue
Canoga Park, California 91303
Attn: Library

North American Aviation Company
S&ID Division
Downey, California 90241
Attn: Dr. James Nash

Oklahoma State University
Stillwater, Oklahoma 74075
Attn: Prof. William L. Hughes
School of Electrical Engineering

Dr. John Owen
P. O. Box 87
Bloomfield, New Jersey 07003

Power Information Center
University City Science Institute
3401 Market Street, Rm. 2107
Philadelphia, Pennsylvania 19104

Prime Battery Corporation
15600 Cornet Street
Santa Fe Springs, California 90670
Attn: David Roller

Portable Power Sources Corporation
122 East 42nd Street
New York, New York 10017
Attn: L. Schulman

RAI Research Corporation
36-40 37th Street
Long Island City, New York 11101

Philco Corporation
Division of the Ford Motor Company
Blue Bell, Pennsylvania 19422
Attn: Dr. Phillip Colet

Radio Corporation of America
Astro Corporation
P. O. Box 800
Hightstown, New Jersey 08540
Attn: Seymour Winkler

Philco-Ford Corporation
Space Power & Prop. Dept, MS W-49
3825 Fabian Way
Palo Alto, California 94303
Attn: Mr. D. C. Briggs

Radio Corporation of America
415 South Fifth Street
Harrison, New Jersey 07029
Attn: Dr. G. S. Lozier
Bldg. 18-2

Southwest Research Institute
8500 Culebra Road
San Antonio, Texas 78206
Attn: Library

Sonotone Corporation
Saw Mill River Road
Elmsford, New York 10523
Attn: A. Mundel

Thomas A. Edison Research Laboratory
McGraw Edison Company
Watchung Avenue
West Orange, New Jersey 07052
Attn: Dr. P. F. Greiger

Texas Instruments, Inc.
P. O. Box 5936
Dallas, Texas 75222
Attn: Dr. Isaac Trachtenberg

Stanford Research Institute
820 Mission Street
South Pasadena, California 91030
Attn: Dr. F. R. Kalhammer

TRW Systems Inc.,
One Space Park
Redondo Beach, California 90278
Attn: Dr. A. Krausz
Bldg. 60, Rm. 1047

TRW Systems Inc.
One Space Park
Redondo Beach, California 90278
Attn: Dr. Herbert P. Silverman (R-1/2094)
Dr. W. R. Scott (M-2/2154)

TRW, Inc.
2355 Euclid Avenue
Cleveland, Ohio 44117
Attn: Librarian

Tyco Laboratories, Inc.
Bear Hill
Hickory Drive
Waltham, Massachusetts 02154
Attn: Dr. A. C. Makrides

Unified Sciences Associates, Inc.
2925 E. Foothill Blvd.
Pasadena, California 91107
Attn: Dr. S. Naiditch

Unio Carbide Corporation
Development Laboratory Library
P. O. Box 6056
Cleveland, Ohio 44101

Union Carbide Corporation
Parma Laboratory
P. O. Box 6116
Parma, Ohio 44130
Attn: Dr. Robert Powers

University of California
Space Science Laboratory
Berkeley, California 94720
Attn: Dr. C. W. Tobias

University of Pennsylvania
Electrochemistry Laboratory
Philadelphia, Pennsylvania 19104
Attn: Prof. John O'M. Bockris

University of Toledo
Toledo, Ohio 43606
Attn: Dr. Albertine Krohn

Westinghouse Electric Corporation
Research and Development Center
Churchill Borough
Pittsburgh, Pennsylvania 15235
Attn: Dr. C. C. Hein

Whittaker Corporation
Narmco R&D Division
3540 Aero Court
San Diego, California 92123
Attn: Dr. M. Shaw

Yardney Electric Corporation
40 Leonard Street
New York, New York 10013
Attn: Dr. Geo. Dalin

Whitakker Corporation
3850 Olive Street
Denver, Colorado 80237
Attn: J. W. Reiter/Borch Wendir

Western Electric Company
Suite 802, RCA Building
Washington, D. C. 20006
Attn: R. T. Fiske

Westinghouse Electric Corporation
Research & Development Center
Churchill Borough
Pittsburgh, Pennsylvania 15235
Attn: Dr. A. Langer